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CONFERENCE PROCEEDINGS

THIRTEENTH DEFENSE CONFERENCE ON NONDESTRUCTIVE TESTING

25-27 SEP 1962

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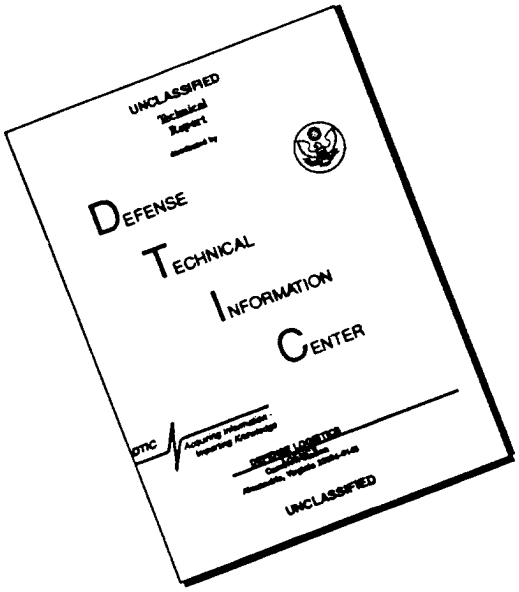

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PROCEEDINGS
OF THE
13TH DEFENSE CONFERENCE
ON
NONDESTRUCTIVE TESTING

25, 26, 27 September 1962

PREPARED UNDER DIRECTION OF

FRANK C. HUND
Technical Director
Quality Evaluation Laboratory

DEFENSE CONFERENCES ON NONDESTRUCTIVE TESTING

Scope.

The coordination of the development and the application on nondestructive methods for the testing and inspection of materials and assemblies for the Department of Defense.

Objectives.

1. To provide for an effective dissemination of information pertaining to nondestructive methods and applications among members and their respective establishments in the Department of Defense.

2. To provide for the utilization of the knowledge, skills, and experiences of specialists in the various branches of the Department of Defense for the attack and solution of problems within the Military establishment.

3. To encourage (wherever applicable) uniform practices in the application of nondestructive testing methods.

Functions.

1. Development of a common report and information distribution list. (Emphasis on individuals rather than on organizations.)

2. Development and distribution of a current bibliography of defense establishment and/or contractors' reports, going back at least to 1946.

3. Development and distribution of abstracts of present and projected programs (Research, Development, and Engineering).

4. Compilation and distribution of useful information such as location, work specialities, staff, and facilities of:

a. Government laboratories or other installations active in the development or utilization of nondestructive testing methods.

b. Commercial laboratories or installations active in the field of interest.

c. Consultants and Contractors active in the field of interest.

5. Evaluation of problems and proposed solutions in conference. The steps which are likely to be taken are:

a. Analysis of the problem in terms of design, engineering, production inspection, and testing history. Such an analysis may be partial before presentation, but should be as complete as possible before specific solutions are detailed.

b. Presentation of problem to conference as a whole or conference panel qualified in nondestructive testing inspection.

c. Liaison between the group in which the problem arises and those qualified, as indicated by conference discussion, to provide assistance in the solution. (Once liaison is effected, the two groups proceed without channeling through the conference.)

d. Report to conference (for the record) the degree of success or failure of the approach taken. If a solution has been reached, the formulation of requirements should be presented.

Organization.

1. Members - Employees of the Defense Establishment concerned with nondestructive testing, inspection, or evaluation, having confidential security clearance.

2. Officers - A secretarial board of not less than three, or not more than seven, who shall be elected yearly by a majority of the conference. This group will serve to receive and transmit information, to act as a steering group, and will elect one of their number as executive secretary.

3. Meetings - The conference shall meet at least once a year at various establishments, as agreed upon between representatives of the establishment and the steering group. The presiding officer at such meetings shall be the conference member whose establishment is acting as host.

THIRTEENTH DEFENSE CONFERENCE
ON
NONDESTRUCTIVE TESTING

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Absent: Bernard Hoffman.

FORWARD

The Department of Defense Conference on nondestructive testing was organized in the Fall of 1951. Twelve meetings have been conducted since that time. These conferences have served to combine the resources of the Army, Navy and Air Force in the field of nondestructive testing through discussion of contemporary problems presented before the conference, exchange of information relating to R and D and new applications and the maintenance of communication between nondestructive testing personnel on a current basis.

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PROBLEM NO. 1

NONDESTRUCTIVE EVALUATION OF DETERIORATION OF STORED TR AND ATR MICROWAVE GAS-SWITCHING TUBES

SUBMITTED BY

NEW YORK NAVAL SHIPYARD
BROOKLYN, NEW YORK

Presented By - S. Goldspiel

A. NAME OF PRODUCT TO BE EVALUATED - TR and ATR Microwave Gas-Switching Tubes.

B. THE KIND OF MATERIAL INVOLVED - This work involves evaluation of subject tubes of various geometries. Generally speaking these tubes are enclosures having one or more transparent window and containing gases and vapors at reduced pressures, including argon, and small amounts of water vapor. They may also contain small amounts of miscellaneous undesirable metallic impurities.

C. THE TYPE OF PROCESS INVOLVED IN MANUFACTURE OF THE PRODUCT - The tubes are composites of wrought or cast frames with one or more transparent plane window sealed into it. The enclosures have been evacuated after closure and small known amounts of gases and vapors introduced into them. The tubes have generally been tested upon completion, as composites, to determine whether their response at the time of manufacture as TR and ATR switching devices is satisfactory. This is generally done with actual microwaves and is rather costly.

D. DESIGN OF PRODUCT - Photographs of typical tubes involved in this problem are shown in Figures 1 and 2.

E. QUANTITY INVOLVED IN NONDESTRUCTIVE TEST EVALUATION - The tube types are used throughout the DOD and are very important parts of radar systems. The numbers involved are estimated in the hundred thousands range.

F. KIND OF QUALITY CHARACTERISTIC WHICH IS DESIRED TO EVALUATE - A nondestructive test method is desired whereby a determination can be made whether tube storage (on the "shelf" or in stock rooms) for indefinite periods affects their proper functioning. The test is to be made without actual excitation with proper frequency microwaves to avoid the relatively high cost and time needed by such tests.

G. MAGNITUDE OF THE QUALITY CHARACTERISTIC NECESSARY FOR SATISFACTORY SERVICE PERFORMANCE - This depends on each individual tube type, and will have to be determined from norms established by suitable concurrent or preliminary development work.

H. BASIS OF JUDGING RELIABILITY - High correlation between nondestructive tests and performance in service, after considerable periods of storage.

I. URGENCY - It is estimated that the problem involves tubes costing from about $25 to $350 a piece, with a total value of several millions of dollars. The current test methods are uneconomical and inadequate. Development of a simple nondestructive test method could result in large savings and introduce a larger factor of operation reliability.

J. FEASIBILITY OF REDESIGN - Redesign is considered not feasible, since no design of tubes operating at reduced pressures can guarantee indefinite shelf life under varying environmental conditions of storage. In addition, a nondestructive method is urgently needed for the currently available stock, regardless of future improvements.

K. PRESENT INSPECTION METHOD - Involves excitation of the tube with microwaves. The response is a necessary but insufficient condition for proper operation.

L. LIMITATIONS OF TESTING EQUIPMENT - Inadequate for reasons stated in K.

M. SECURITY CLASSIFICATION - UNCLASSIFIED.

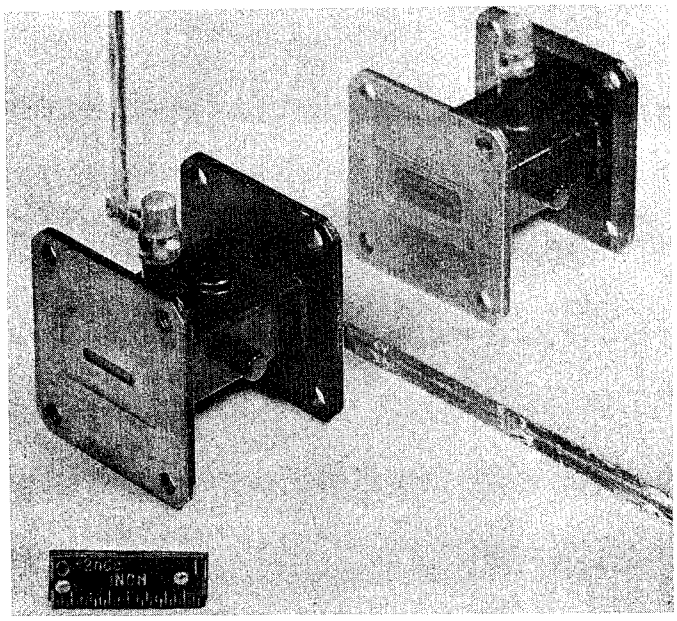


FIGURE 1 ATR TUBE (AND MIRROR IMAGE)

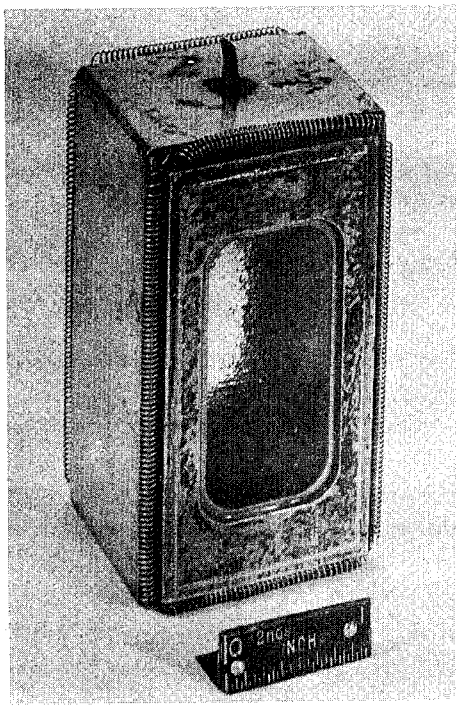


FIGURE 2 TR TUBE
MICROWAVE GAS-SWITCHING TUBES

Suggested Solution to
PROBLEM NO. 1

NONDESTRUCTIVE EVALUATION OF DETERIORATION OF STORED TR AND ATR MICROWAVE GAS-SWITCHING TUBES

Prepared By - I. J. Feinberg

From the presentation and the discussion that ensued, the following information was elicited as regards the problem of developing a nondestructive method for testing TR and ATR tubes. The problem concerns two types of tubes.

1. A gas filled tube which is a simple resonant cavity ionization chamber. See Figure 1 (Photo not included).

2. A gas filled tube which in addition contains a "keep-alive" element used to trigger ionization. The "keep-alive" element is frequently coated with Co-60. See Figure 2 (Photo not included).

The tubes in effect function as spark gaps excited by the proper frequency of microwave power. They effect an open circuit when not fired and a short circuit when fired. (See Figure 3.)

The filler gas is composed of a medium which is ionized to act as the current conductor (such as Argon); and a quenching medium to facilitate recovery when microwave excitation is removed (such as water vapor). The effectiveness of the tubes in protecting receivers may decrease with age of the tube because of a gradual decrease of the pressure. The gas is gradually consumed by chemical combination and absorption in the electrodes and tube walls under the influence of the glow discharge. This is especially the case in the "keep-alive" tube type.

As the tube is used, the gas is consumed gradually, and the gas pressure falls. Below a critical pressure level, higher (undesirable) gap voltages are required. The protection gets less very rapidly as the pressure decreases. If the TR tube is used or stored for a very long time, a point is reached at which the transmitter cannot fire the gap at all. The tube is worthless for receiver protection and must be replaced before this point is reached.

TR tubes become useless for another reason. The process by which gas is absorbed from the tube is selective. Thus the quenching medium, such as water vapor, may be absorbed more rapidly than the carrier gas which is usually a noble gas (such as Argon), and as a result the recovery time is increased. The reason for replacing TR tubes is often excessive recovery time. Deposition of metal films emanating from the electrodes on the inside envelope, due to sputtering, also affects the life of a TR tube by changing the impedance value of the chamber and reducing the echo signal supplied to the receiver. However, this does not affect the protection for the receiver.

The satisfactory performance of TR and ATR tubes is determined by the following factors which must be measured for each tube type by actual microwave tests:

1. Leakage Power - During the transmitted pulse the power getting past the TR tube into the receiver must be less than 0.1 watt to avoid damage or burn out of the crystal, see Figure 4.

2. The TR tube must fire in less than 0.01 microsecond, or a preignition spike of transmitter power will be allowed through to the receiver and burn out of its sensitive crystal, see Figure 4.

3. The gap must deionize in a few microseconds so that echoes from near by objects will not be unduly attenuated. A typical specification calls for an attenuation of less than 3 db 6 microseconds after the end of the transmitted pulse.

4. The received signal must see a reasonable good match into the receiver and the losses must be kept to a minimum.

Present Inspection Method - To afford protection of the receiver, 100% inspection is required. The frequency of inspection depends on the actual firing time as well as the storage time between using the tube in firings. While the normal life of tubes ranges from 500 to 1000 hours, indeterminate shelf storage may deteriorate tubes which have not been used at all. For this reason all tubes must be checked frequently. The method currently employed requires elaborate microwave setups. Measurements are made, in this connection, of the following parameters:

1. Recovery time

2. Leakage power

3. Firing power

4. Arc loss

5. Noise generated

A nondestructive test must be able to reflect the life of the tube by establishing correlations with changes of tube gas filler as it affects the above electrically determined parameters. The nondestructive test method must also bear a high correlation with results obtained by currently used methods at low and high levels of excitation with microwaves of applicable frequency.

PROPOSED SOLUTIONS

1. Basic to the development of any nondestructive method, it is considered essential that preliminary test work be conducted by use of the current electronic methods to establish norms, with due consideration of statistical variability. In addition, tubes for each type must be found which provide representative departures from norms due to various inherent flaws. For this purpose data on recovery time, leakage, arc loss, noise, etc. would have to be derived by the use of tubes in actual low and high energy microwave setups. Good and bad tubes are needed in preliminary exploration and subsequent calibration work for various nondestructive tests.

2. Suggested approaches obtained from conferees, not necessarily in order of feasibility, are as follows:

a. External Ionization Source and Externally Applied Voltage(1) - The parameter to be measured for correlation with change in gas content, which affects acceptability of the tube under test, would be current or recovery time. This could be accomplished by the use of microammeters, oscilloscopes or rate meters. The external ionization sources could be low voltage X-rays or low Mev radioisotopes. This method would be applicable exclusively to tubes with "keep-alive" electrodes. One conferee(2) expressed doubt as to whether tubes discriminated on the basis of low activity external ionization would yield data on recovery and leakage which would correlate with performance at low and high level microwave operation.

b. Optical Spectroscopy - The tube gases will be excited by the use of low energy (externally applied) microwaves. The criteria to be explored in this test would be the examination of emission spectral lines and intensities for various components of the tube filler gases of acceptable and defective tubes as determined by actual microwave test parameters developed in preliminary work cited in paragraph 1. This approach follows the lines of approach in the preliminary work by Bomarc and the Material Laboratory. If feasible, the method would apply to tubes with and without "keep-alive" electrodes and with one or two windows. The anticipated difficulties are dependent on (1) the ability to obtain spectra with adequate sensitivity under excitation conditions mentioned, and (2) control exercised over the thickness and quality of the tube windows in the original manufacture.

c. Mass Spectroscopy - A sample of the gas filler would be extracted from the tube under test into a chamber pumped to a vacuum sufficiently below the level of pressure maintained in the tube tested. A comparison will be made between relative amounts of gases in good and bad tubes as determined with actual microwave tests. Norms for variation in gas makeup of good tubes would be established as basis for discriminating bad tubes. The method will be limited by the ability for nondestructive extraction of samples of tube gas filler content. If feasible the method should be applicable to all tube types, regardless of whether or not they have the "keep-alive" element and one or two windows.

d. Infrared Absorption Spectroscopy - In this method an external infrared source would be applied to the tube and comparison made of the absorption lines for good and bad tubes, as determined by actual microwave tubes. The method would be limited by (1) the sensitivity of absorption lines and bands of the various filler components and their breakdown components, and (2) the closeness of control exercised over the quality and thicknesses of the tube windows. Tubes with two windows might be more readily tested by this method. If feasible, the method could be adapted to tubes with one window by the use of reflected radiation from inside (far side) wall, as for example by use of prisms.

e. Resonance Excitation of Quenching Medium[3] - This method would require preliminary exploration to determine for each tube type the gas or vapor component which acts as the quenching medium. The tube under test would be excited with a primary source containing the quenching medium characteristic wavelengths. With this as a source the intensity of resonance produced by the filler component in good and bad tubes (as determined by actual microwave tests) would be compared to establish limits for good tubes.

Footnotes:

(1) Method suggested by C. G. White, Picatinny Arsenal, Dover, N. J. and tried by Material Laboratory, New York Naval Shipyard with low voltage X-rays from a conventional X-ray spectrometer, on a good tube only.

(2) H. A. Baller, U. S. Army CBR, Quality Assurance Group, Edgewood Arsenal, Md.

(3) J. Holloway, Naval Ordnance Laboratory, Silver Spring, Md. Methods (b), (c) and (d) stem from suggested approaches considered as possibilities by the Material Laboratory, N. Y. Naval Shipyard, and concurred by conferees.

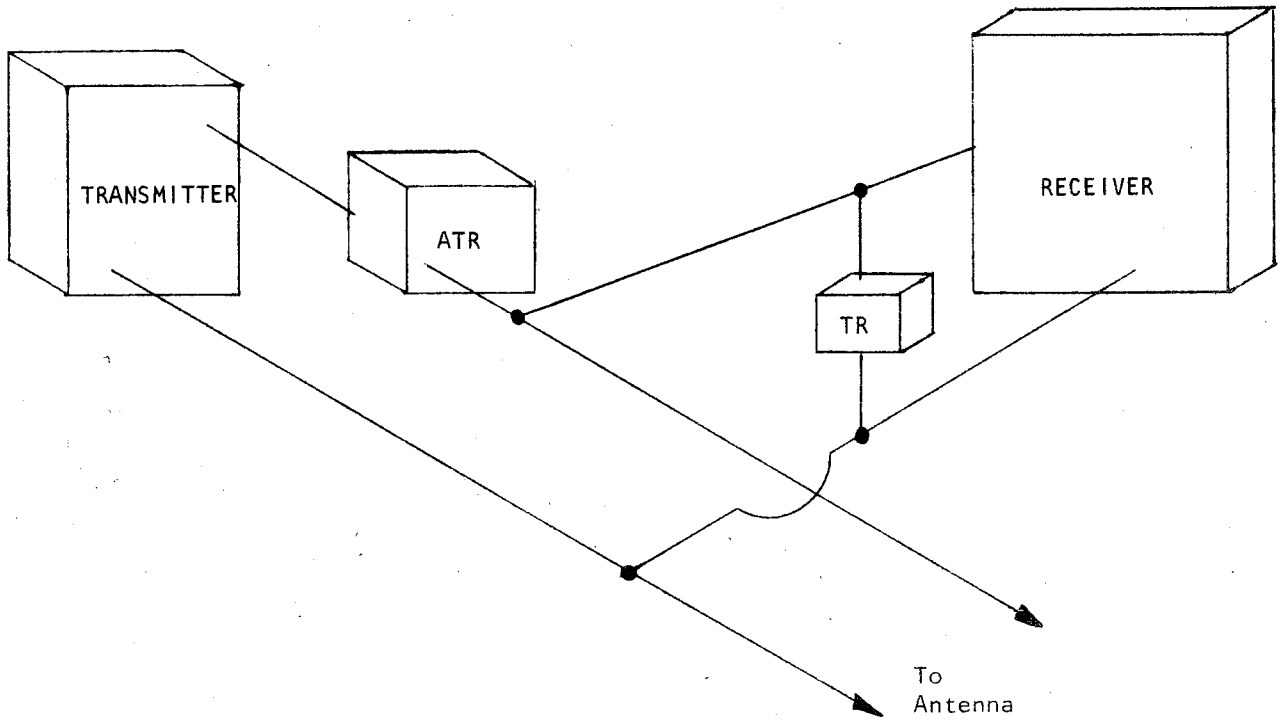


FIGURE 3
Schematic Diagram of TR and ATR Switching Tube

TR = transmit-receive tube (switch disconnects receiver during transmission)
ATR = anti-transmit-receive (disconnects transmitter during reception)

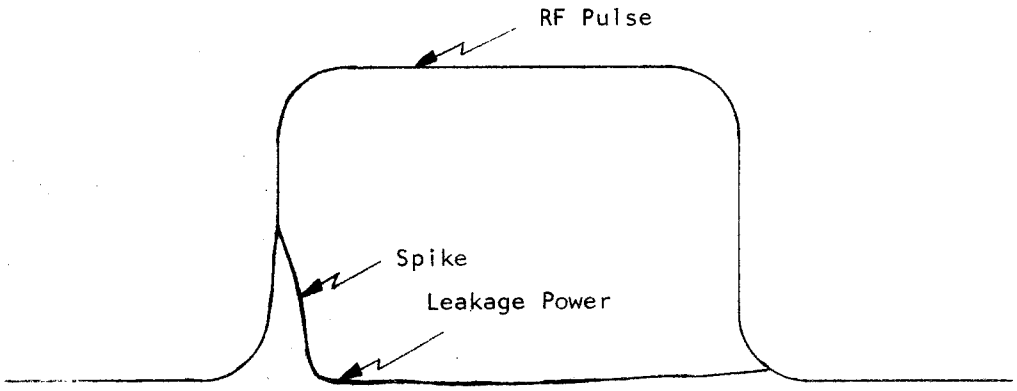


FIGURE 4
Typical Spike and Leakage Power through a TR Tube

PROBLEM NO. 2

QUALITY OF WELD BOND AND PRESENCE OF BLOW HOLES IN RESISTANCE BUTT WELDED BALL ASSEMBLY OF 40 MM, M407 CARTRIDGE

SUBMITTED BY

PICATINNY ARSENAL, DOVER, NEW JERSEY

Presented By - D. J. Molella

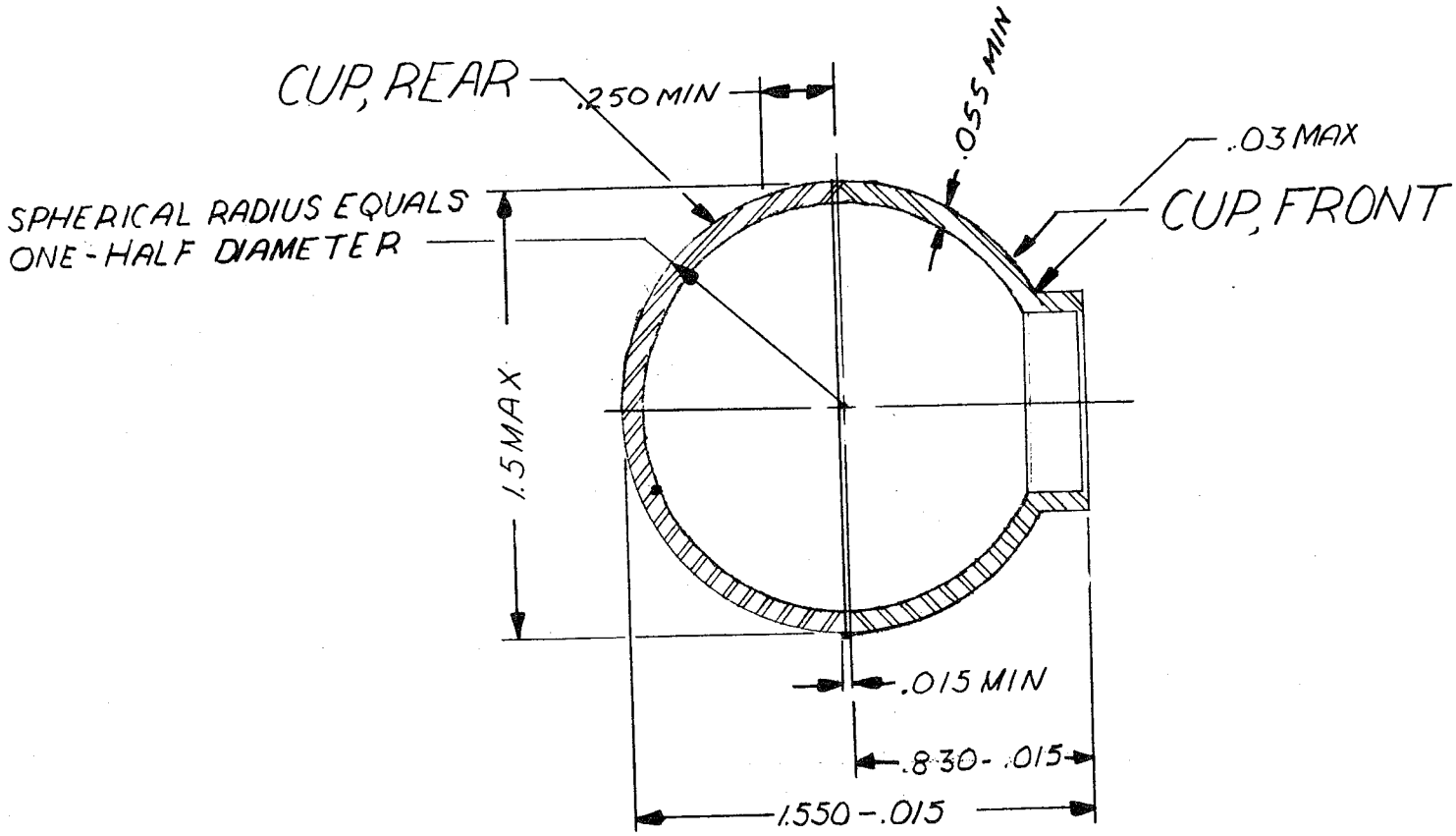
The first slide shows a sketch of the ball assembly for which a non-destructive test is desired. As is evident from the sketch, the interior of the assembly is accessible through a 1/2 inch opening. The assembly consists of two hollow hemispheres which are cold-forged from aluminum killed, 1007 to 1015 deep draw quality steel strip .067 inch thick. The hemispheres or cups are resistance butt welded in the as-forged condition with no subsequent stress relief. Weld flash is trimmed off at the equatorial outer surface. Interior surfaces are coated with acid proof black paint. About one quarter million assemblies per year or about 20,000 assemblies per month are produced.

It is required that at least 80 percent bonding of the butt welded cups is necessary for satisfactory performance and service. The present inspection method is to subject two assemblies from each welding station at the start of each shift and one assembly each hour during the shift to a Crush Test and then inspected visually. The Crush Test consists of flattening the assembly to a height of 0.5 inch by application of a transverse compressive load. The second slide shows the assembly before and after welding and after subjecting to the Crush Test. After the Crush Test accumulative blow holes of 3/8 inch maximum are permitted. Tears of the parent metal are permitted at the blow holes but no cracks are permitted anywhere. Failure of one assembly constitutes rejection of the entire hour's production. After rejection and after corrective action, 10 consecutive assemblies from that Station must pass the Crush Test before proceeding with production.

Macroscopic examination of cross sections of the assemblies after welding revealed that there was insufficient fusion of the parts along the circumference at the inner surface which resulted in a notch there, as shown in the third slide. Microscopic examinations disclosed that there was only about 10 to 30 percent fusion at the joints with the balance possessing a mechanical bond, as shown in the last slide. It appeared that insufficient heat was being generated at the interface. The welding problem was further aggravated by the presence of blow holes which are formed at the weld joint because of the reduction in the wall thickness at two points in each of the cups of the assembly. These thin areas correspond to the two points where the strip is held in place during the cold forging operation. By lowering the welding force from 2500 to 2000 pounds and reducing the current, better fusion was obtained and the incidence of blow holes was reduced. However, occasional blow holes

are still encountered because of varying degrees of thinning of the wall from one ball assembly to another. At the present time about 70 percent of the assemblies tested pass the Crush Test. Numerous assemblies are now undergoing firing tests and it is expected that the present requirement of the Crush Test can be relaxed to permit a limited amount of cracking as determined by the results obtained after crush and firing tests.

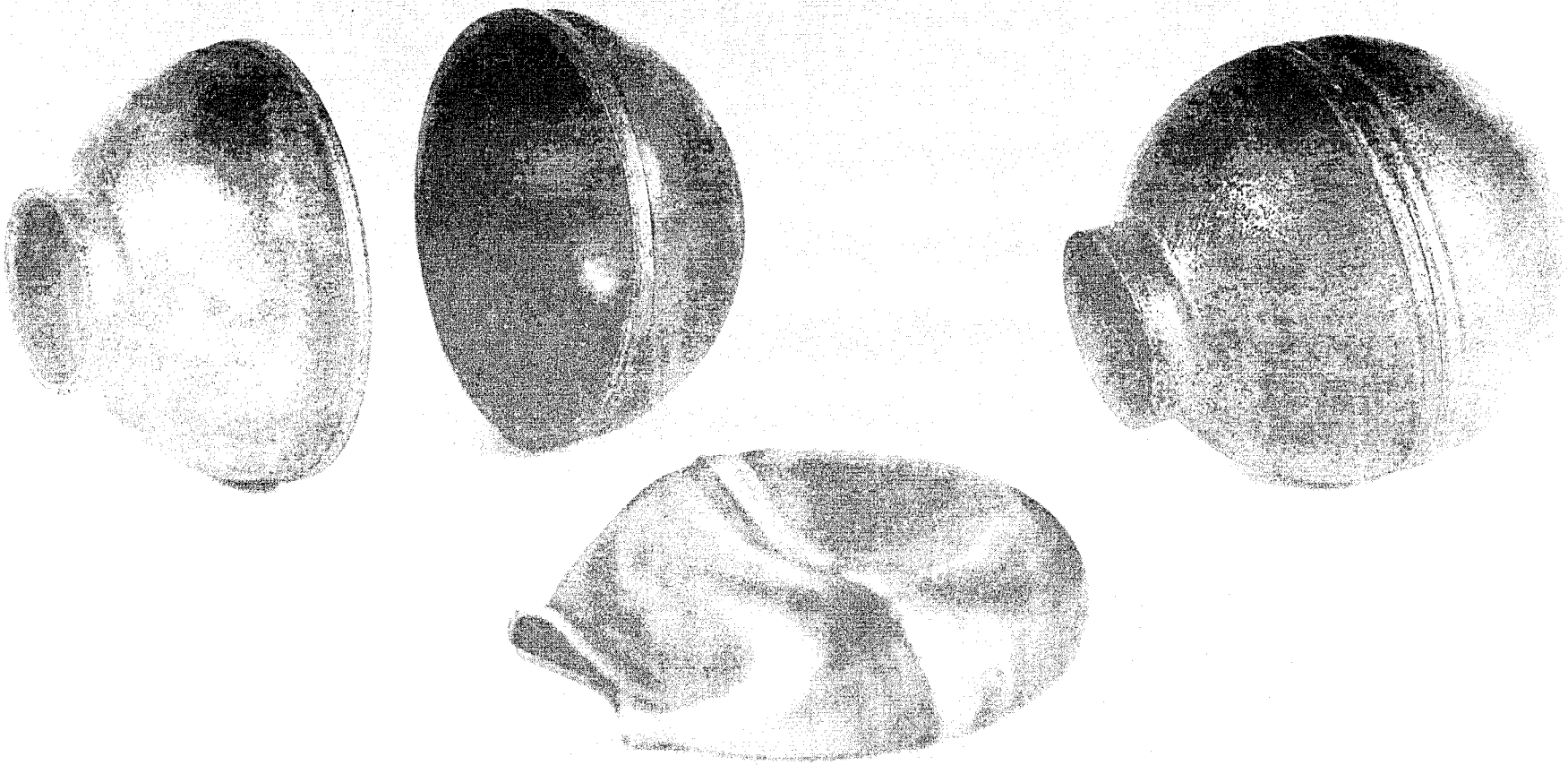
Since improper functioning of the ball assembly can cause injury to personnel, a highly dependable nondestructure test of at least 99.9 percent reliability is urgently needed which will enable 100 percent inspection.



COAT INTERIOR SURFACES WITH ACID PROOF BLACK PAINT, TYPE I, SPEC MIL-P-450.
MAX MISMATCH BETWEEN FRONT AND REAR CUP .01 BEFORE SHAVING EQUATORIAL AREA.
MATERIAL :- STEEL, ALUMINUM KILLED, STRIP, 1007 TO 1015, DEEP DRAW QUALITY, SPEC OAC-PD-32. .067 ±.003 THICK.
.055 MIN WALL THICKNESS TO EXTEND FOR A DISTANCE OF .250 MIN.

BALL ASSEMBLY, BUTT-WELDED (RESISTANCE)

SLIDE NO. 1



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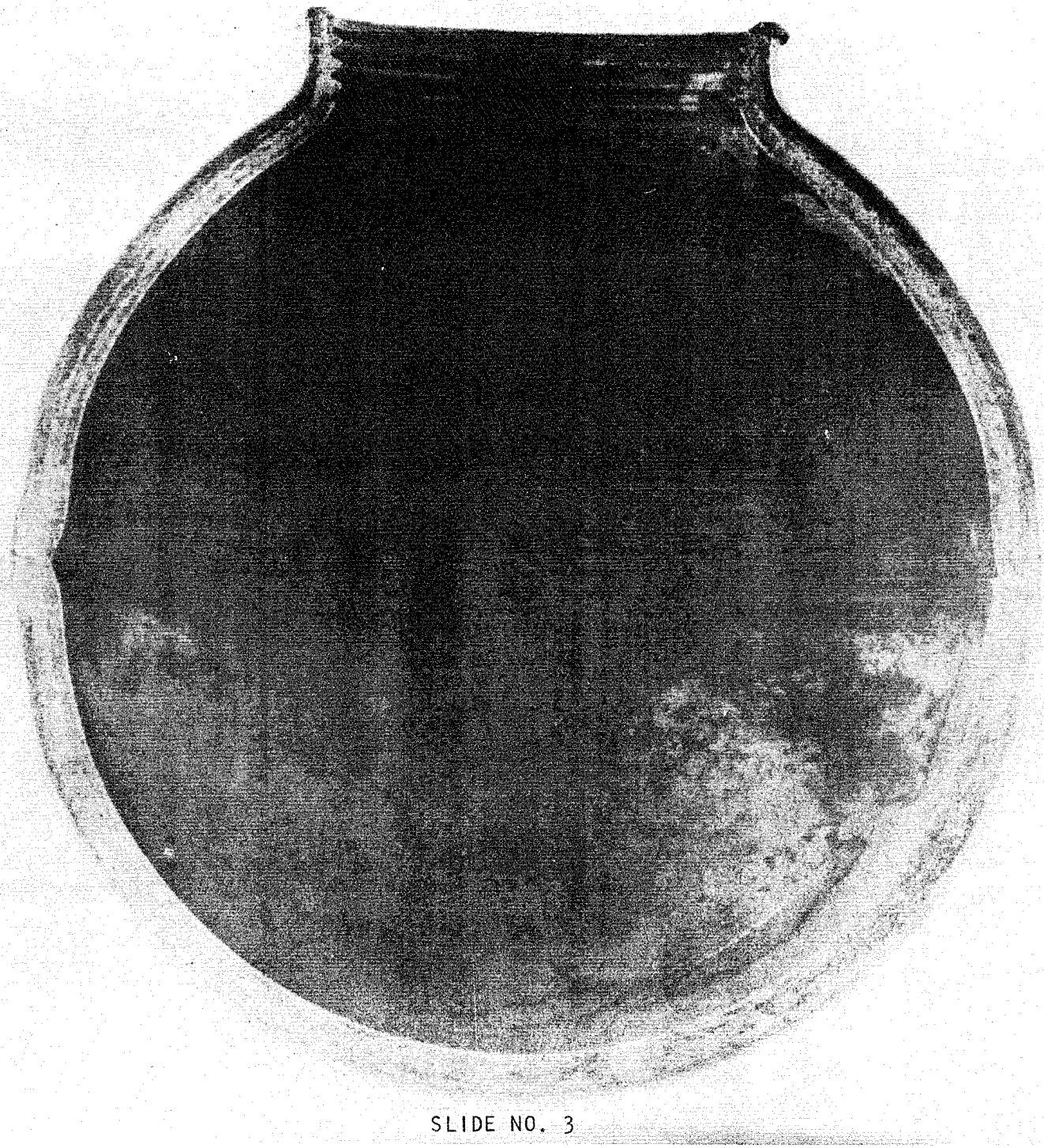

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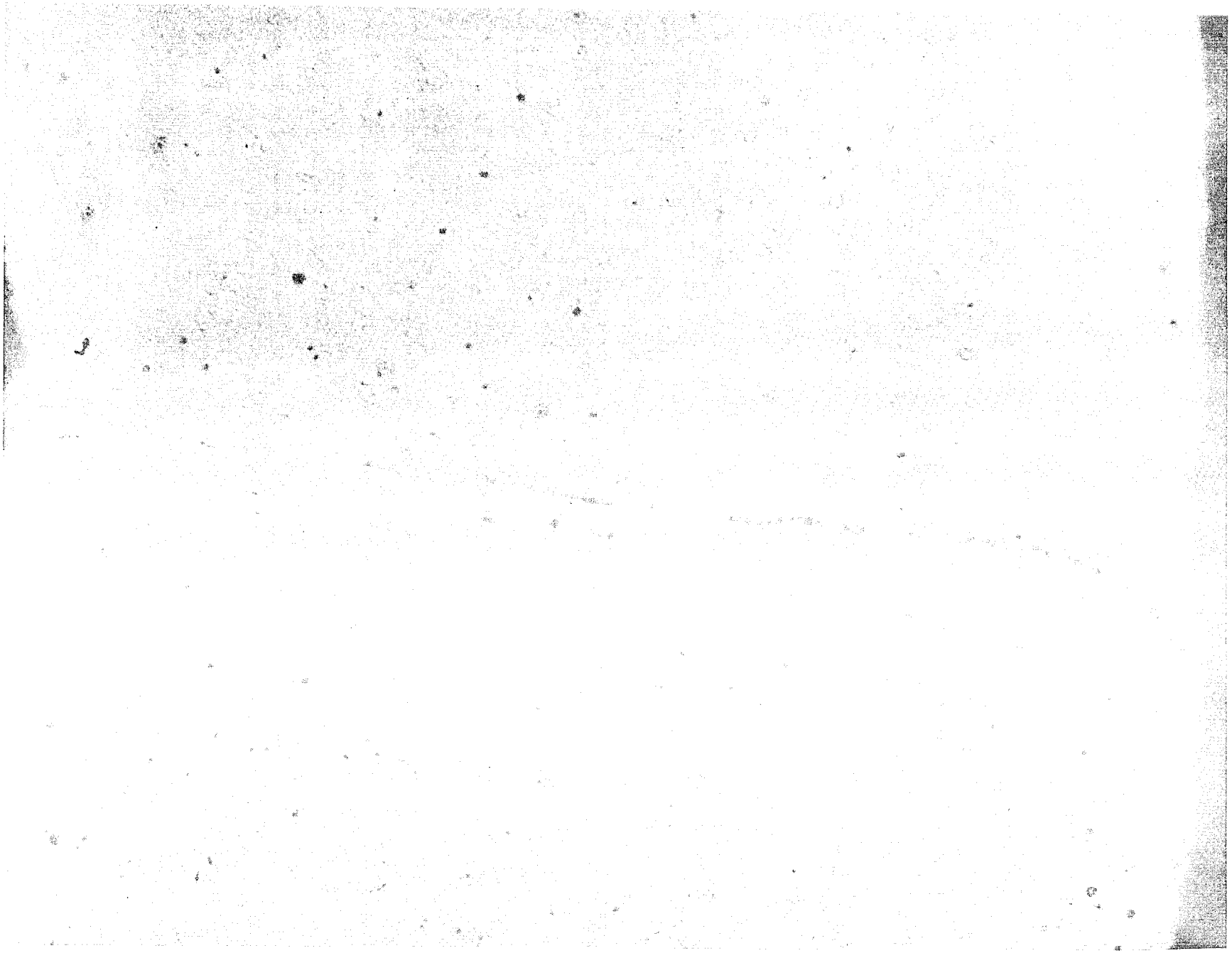


SLIDE NO. 4

Suggested Solution to
PROBLEM NO. 2

QUALITY OF WELD BOND AND PRESENCE OF BLOW HOLES IN RESISTANCE BUTT WELDED BALL ASSEMBLY, 40MM, M407 CARTRIDGE

Prepared By - H. A. O. Baller

The problem is to determine the integrity of the weld bond and to detect blow holes in the resistance butt weld of two hollow hemispheres, cold-forged from a specific kind of strip steel; at least 80% bond or 3/8" total accumulation of blow holes is required for the item to be acceptable; the method currently in use is a comparatively slow destructive test and visual inspection.

The magnitude of production practically dictates that automated methods of inspection be applied, capable of rapid detection of the kinds of defects mentioned with a high degree of reliability. Almost any detection method, once developed and proved, can be automated, to varying degrees, by simple application of mechanics utilizing the outputs of the detection methods.

To this end, then, (and not for this problem alone), any of the suggested approaches first must be investigated for primary feasibility. Should feasibility be indicated, then further investigation should soon reveal if the method provides the outputs, or kinds of information that are needed for the required mechanical manipulation or operation. Simply applying certain basic methods, or techniques, such as radiography, is not enough: Radiographic examination can give the necessary information but is too slow to even be considered in its basic form for application in the specific case.

In any case, extensive testing can be expected to have to be done with known or developed standards from which data can be taken which in turn will have to be correlated with limitations established by initial requirements.

Following are additional salient points pertinent to the item and problem, as well as some of the suggested approaches:

1) Sectionalizing has revealed that the bond can, and does, fluctuate in varying degrees of quality around the circumference. That is, certain types of defects do not always occur in the same spot or area in any given number of sample spheres: Their incidence of occurrence is neither fixed nor predictable.

2) The defects when they do occur, are not always visible on either the inside or the outside surfaces of the sphere.

3) Porosity can and often does occur entirely between and not through the wall surfaces and precludes the application of hydrostatic tests.

4) The application of certain basic techniques has been suggested: All are believed to be capable of giving some kind of indication, but most are thought not to be feasible for high speed application. They are: a) introduction of gamma sources to produce radiographs. b) radiographic. c) radioactive source (internal) with geiger counter. d) magnetic particle.

Three approaches appear to have sufficient merit to warrant further investigation: They employ eddy current, ultrasonic and magnetic field techniques.

The eddy current method could be applied in a manner similar to that employed in equipment developed at Frankford Arsenal for the detection of flaws in the 20mm shell body.

This equipment uses a differential probe capable of performing tests with a high degree of resolution. Through the integrating circuitry it should be possible to add the voltages obtained in a quantitative manner. Based on correlation tests made on established standards, accept and reject levels can be set as a part of a fully automated system[1].

The ultrasonic method would employ the shear-wave technique, using the Thru-ray, with transducers positioned on either side of the bond and a collimated beam (1/4" or 1/8") while the sphere is rotated. Simple recorder output can be obtained showing downward deflection whenever the beam intensity at the receiver decreases causing a reduction of voltage toward a present level which has previously been determined from a standard sample of a porous area or crack. The material is thin enough (.067) to make this method feasible[2].

The magnetic field technique would involve two coils: One coil applied to a standard sphere and the other coil to the sample to be tested. A magnetic field is set up to establish a hysteresis loop. Defects would show up as decay in the hysteresis loop. There could be employed a gating system to be activated by pre-setting to amount of decay in the hysteresis loops[3].

Other observations and comments not directly associated with nondestructive testing:

Reportedly, no other welding techniques have been investigated. It is believed that the properties of the material are such that ultrasonic welding should be able to be applied[4].

Explosive forming could be a means of producing a seamless sphere thereby eliminating the source of the problem.

Cleaning of the welding electrodes has resulted in a reduction of detectable defects (using the destructive test) and almost eliminated visible discontinuities for a given production run. The use of clean electrodes should be a quality control point stressed in the manufacturing process.

Footnotes:

1. Eddy Current Method of Testing 20mm Shell Body: Mr. Eugene Roffman. Frankford Arsenal, Philadelphia, Pa.
   Additional information and details available.

2. Ultrasonic Testing by Shear-Wave Technique: Mr. L. C. Cardinal USNRL Code 6254, Washington 25, D. C.
   Mr. Cardinal has offered to test this approach if samples can be provided.

3. Hysteresis loop technique is a function of the Magnaflux FS-310.

4. The Navy has done a considerable amount of development in the field of ultrasonic welding. Details and assistance can be obtained from Mr. Roy Gustafson, BuWeps, RRMA24, Main Navy, Washington 25, D. C.

PROBLEM NO. 3

DETECTION OF CORROSION IN AIRCRAFT INTEGRAL WING TANKS

SUBMITTED BY

OKLAHOMA CITY AIR MATERIEL AREA
TINKER AIR FORCE BASE, OKLAHOMA

Presented By - A. L. Sharp

SCOPE: USAF needs a better corrosion detection process.

A. What is an integral fuel tank?

1. Uses wing structure as fuel storage space.

a. Structural joints sealed during assembly with nonhardening compounds.

b. Top coatings are applied to protect structure.

c. Has greater space than bladder or individual tank types.

d. Reduces weight of aircraft.

B. Description of typical wet-wing aircraft with corrosion problem.

1. Usually high gross weight.

a. Tanker.

b. Bomber.

c. Cargo.

d. Fighter.

2. Majority of wing constructed of high strength aluminum alloys.

a. 7178-T6.

b. 7075-T6.

C. Usage of typical wet-wing aircraft with corrosion problem.

1. Continuous flying status to long periods of loaded alert.

a. High and low level flying.

b. Refueling.

2. Climate variation.

a. Desert.

b. Sea coast.

3. High usage requires short maintenance periods.

a. Down time must be a minimum.

D. Causes of fuel tank corrosion.

1. Chemical and galvanic reactions.

a. Contaminants.

(1) Inorganic acids, dirt, metal chips, water.

(2) Organic microorganisms.

E. Results.

1. Material break down.

a. Reduction in cross section.

b. Stress raising discontinuities.

F. Preventing corrosion.

1. Decontaminate fuel.

2. Barriers.

a. Mechanical.

b. Chemical.

3. Preventative maintenance.

a. Periodic inspections and cleaning.

(1) Early detection.

(2) Minor repair.

G. Status.

1. Detection methods used.

a. Radiography.

b. Ultrasonics.

c. Visual.

d. Magnetic fields.

2. No completely satisfactory process to date.

H. USAF needs.

1. A corrosion detection process which is:

a. Quick.

(1) Reduce down time.

b. Accurate.

(1) 3% to 5% error.

c. Simple.

(1) Semi-skilled operator.

d. Portable.

(1) Minimum of crew.

(2) Light weight.

(3) Rugged.

Suggested Solution to
PROBLEM NO. 3

DETECTION OF CORROSION IN AIRCRAFT
INTEGRAL WING TANKS

Prepared By - William Sheppard

1. Several methods of possible detections of corrosions in these tanks were suggested. Since none of the conferees had attained experience on an identical problem, information offered will require investigation prior to adoption by this Air Force activity.

2. The introduction of test plates (7178 Aluminum) which have been rendered radioactive through immersion in a neutron flux was offered by Mr. Cecil G. White of Picatinny Arsenal. Mr. White proposed that such a plate be installed within the wing tank at a specific corrosion sensitive area. This plate, in turn, could be monitored from beneath the wing area with a gamma probe. A loss of gamma activity exceeding normal decay would indicate a loss of mass and thereby an effect of corrosion. Mr. White suggested Watertown Arsenal as a source of the neutron flux.

3. Another promising suggestion was that offered by Mr. John W. Orner. He suggested a specific ultrasonic technique. This technique would place an ultrasonic source transducer in the near vicinity of the questionable area and on the opposite side. This source would be placed so that ultrasonic waves could be induced at a very low angle to the sheet metal plane. Resultant waves would be monitored by a probe placed on the sheet metal at any location "down stream". The presence of wave scatter would indicate surface irregularities on either side of the sheet metal plate.

4. Mr. Phillip Cambis from Edwards AFB cited similar cases where borescopes had been used advantageously. He recommended that manufacturers of borescopes could advise on types that would, because of configuration, be adaptable to the wing cavity problem.

5. Several suggestions were offered for the application of corrosion protective sealants to replace or supplement those now being used. Dr. Charles P. Pickett at Aberdeen Proving Ground, Md. was cited as an expert in this area.

6. Mr. Eugene Roffman of Frankford Arsenal is to forward reports acquired through the investigations of corrosion detection on magnesium plates.

PROBLEM NO. 4

DETERMINATION OF PROPER SEATING OF ROTATING BANDS FOR 105 MM HE STEEL SHELL

SUBMITTED BY

PICATINNY ARSENAL

Presented By - D. J. Molella

One of the purposes of the rotating band is to provide a gas tight seal against the propellant pressure as the shell travels through the gun barrel. If the band is improperly seated on the shell, the propelling gases can escape. There is also the possibility of the rotating band becoming loose or separating from the shell and consequently damaging equipment or injuring personnel.

The sketch in the first slide shows the dimensions of the rotating band and the band seat. Testing of the rotating band is complicated by the undercut shape at the edges of the band, by the tapered surfaces and by the presence of three pyramidal ribs located across the band and around the circumference. There is also a variance in wall thickness of the shell which supports the rotating band, as shown in the second slide. Testing is further complicated by relatively wide variations, about $\pm$.020 inch, in the thickness of the band due to the tolerance on the diameter of shell, diameter of the rotating band seat and on the band after it has been turned down to size.

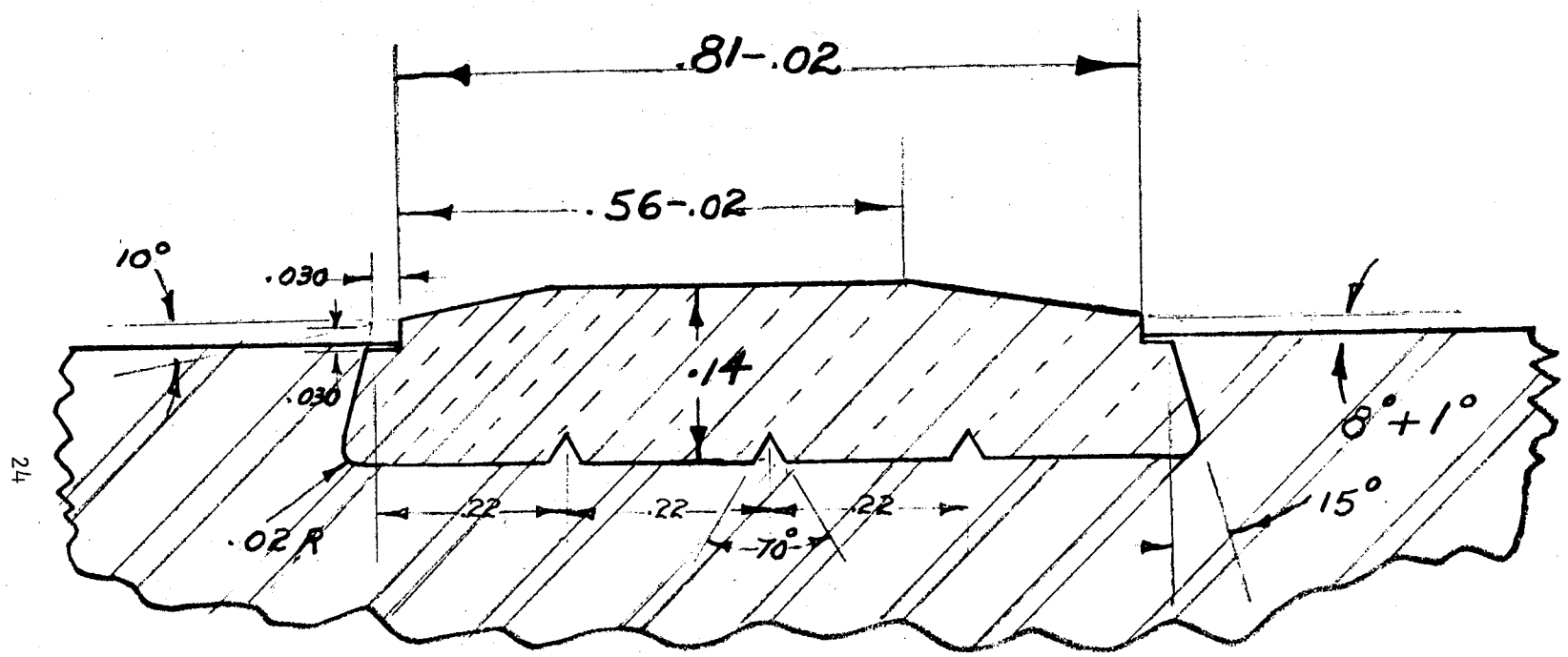
Formerly most of the rotating bands were made from a wrought copper alloy (gilding metal) containing 90 percent copper and 10 percent zinc. At the present time sintered iron having a specific gravity of 5.96 and which is impregnated with paraffin is used as the band stock metal. In the case of the copper band, a six jaw press is used to cold press the rotating band on the shell. The band is squeezed three times and after each time the shell is rotated 30 degrees. When sintered iron stock material is used, the band is cold pressed on the shell in one squeezing operation with a 24 jaw press. Upon pressing, 30 percent cold reduction results and the specific gravity of the sintered iron increases from 5.96 to 6.40. As shown in the last slide, the band still contains some porosity so that the band will be compressible as the shell travels through the gun. This compressibility, plus the presence of the paraffin which acts as a lubricant reduces erosion and wear of the gun barrel.

Present inspection requirement specifies that there shall be a minimum of 80 percent fill at the undercut. There is also a tentative requirement that a gap at the bottom of the band should not be more than .001 inch wide nor longer than 1-1/2 times the width of the band. For the 105 MM shell band the allowable length is about .88 inch. Two inspection methods are now used to test the band. One method is a destructive test which consists

of visually examining a very few sectioned shells from each production lot. The other method is a mechanical test where a Detroit Testing Machine Co. Model RB1 tester is used with which a load is applied to the rotating band and the gap size is determined by the amount of movement of the band. However, this method is slow and expensive and in insensitive to short and small gaps. Since one of the purposes of the rotating band is to achieve a gas tight seal, it would seem obvious to inspect them by measuring leakage of gas past the seating of the band. This type of testing, however, would be expensive and not practicable in that the shell is not subjected to the service stresses during this test which would tend to cause leakage. Radiographic methods can detect gaps but these methods are slow, expensive, have limited sensitivity and interpretation is difficult in borderline cases.

The English have done some extensive work in developing nondestructive tests for determination of gaps in copper rotating bands on their 120 MM high explosive shells. They have developed a method which utilizes a solenoid electromagnet in conjunction with a 5 mc/s barium titanate flaw detector probe. The electromagnet is placed in contact with the band and then subjected to an electrical input so that the solenoid hammers (vibrates) the band at 25 pulses/sec. The barium titanate crystal is also placed in contact with the band and positioned at 45 degrees from the electromagnet and the shell is rotated so that the cathode ray tube readings can be taken around the entire circumference. The vibration amplitude of the band for a given input will rely upon the stiffness of the band which in turn depends upon how efficiently the band is seated on the shell. The English claim that this equipment will detect gaps beneath the rotating band and that the method is rapid and simple. With this method, however, the gap size cannot be determined. This method is being used in England in conjunction with a mechanical test in which a weight is dropped on the band and the time for the band to seat on the shell, assuming the presence of a gap, is measured accoustically. By this means the length and width of the gap is determined. It is doubtful whether any of these methods are practical in the case where the band is made of sintered iron which contains porosity.

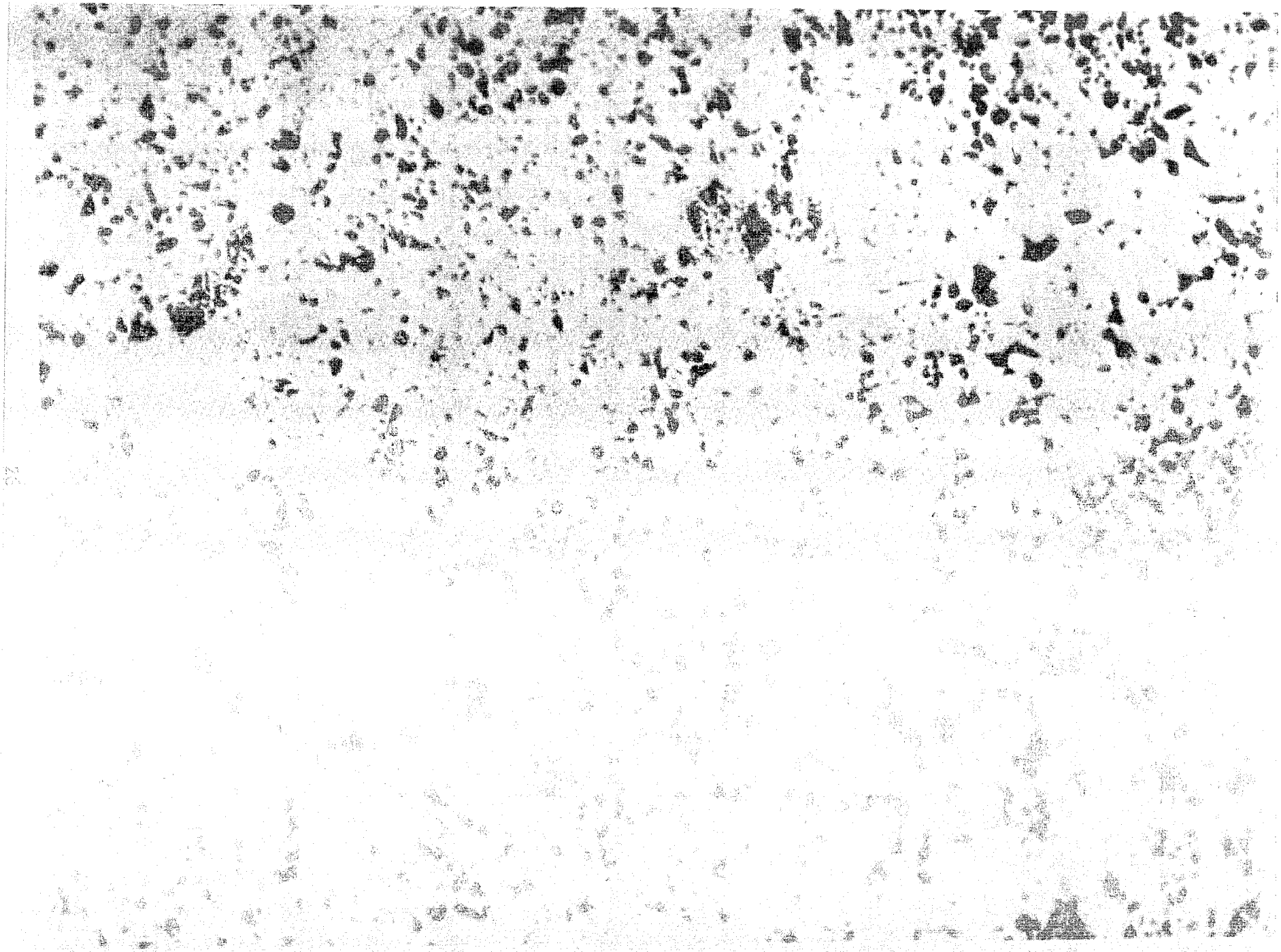
At the present time the shell are produced in lot quantities from 200 to about 2000 at a mass production rate of from about 10,000 to 100,000 per month. Since improper seating can cause loss of band in flight with consequent inaccuracy which might endanger friendly troops, a nondestructive test having a reliability above 99 percent is needed. The need for the test method is immediate in order to insure satisfactory production and permit 100 percent inspection.



ROTATING BAND, SINTERED IRON FOR SHELL, HE, 105 MM

SLIDE NO. 1

SLIDE NO. 2



SLIDE NO. 3

Suggested Solution to
PROBLEM NO. 4

DETERMINATION OF PROPER SEATING OF ROTATING BANDS FOR 105 MM HE STEEL SHELL

Prepared By - Carl Martin

I. BACKGROUND

A. A rotating band has two primary functions; to transmit rotational energy for spin-stabilization of the projectile, and to provide a gas check to prevent bypass of the propellant gases. In order to perform these functions the rotating band must have adequate physical strength, be firmly fitted to the shell, be soft enough to conform to the lands and grooves of the rifling and have low abrasive characteristics. As designed, the band may be made either of copper base alloys or sintered iron. It is cold-pressed into an undercut, serrated groove on the periphery of the shell. The applicable specification requires that after pressing, 80 percent of the undercut be filled.

B. Present Methods of Test

Two test methods are prescribed. In one method samples selected from a lot are sectioned at several points and subjected to visual inspection. In another method, a load is applied and the movement of the band under load is used as an indication of the gap size. The first method is destructive and the second is not suitable for use on sintered iron bands. In addition to these methods, the British have a technique involving the use of low frequency, high energy vibration. The vibration amplitude is a function of stiffness which in turn is a function of seating efficiency. Gap size is determined independently by applying a force to the band and measuring the time-to-seat. This technique is not considered applicable to sintered iron bands because of their porosity.

II. PROPOSED SOLUTIONS

A. Several possible approaches to the problem were presented and discussed. The following were considered the most promising and it has been determined that facilities are available for their investigation:

1. Magnetostrictive testing has been applied at Frankford Arsenal in resolving related problems. When used with appropriate standards, it should be feasible to locate and evaluate voids between the rotating band and the shell by this method.

2. A method based on use of sonic frequencies has been applied to similar problems by the Naval Research Laboratory. Equipment for making investigative tests is available at this site. Frankford Arsenal has also used this technique, and information is available.

III. CONCLUSIONS

In the opinion of the Problem Coordinator and his Technical Consultants, if either of the foregoing methods proves to be applicable, the design of equipment for nondestructive production inspection should offer no particular difficulty. It should also be possible to improve on and adapt the British method to production inspection.

IV. CONTACT POINTS

At Frankford Arsenal, Philadelphia, Pa.
Mr. Eugene Roffman, SMUFA-1120
Chief Engineering Laboratory Branch
Mechanical & Electric Inspection Div.
R&D Group - Pitman Dunn Labs

At Naval Research Laboratory, Washington 25, D. C.
Mr. Stephan D. Hart, Code 6254

PROBLEM NO. 5

M14 RIFLE FIBERGLAS-REINFORCED PLASTIC STOCKS

SUBMITTED BY

SPRINGFIELD ARMORY, SPRINGFIELD, MASSACHUSETTS

Presented By - J. Szanto

Material - Fiberglas Reinforced Plastic, combination mat and premix, 2-piece molding assembled with epoxy polyamide adhesive, hollow butt end filled with rigid Urethane foam.

Process - High compression molded, then accurately assembled in jigs, and finished with Urethane surface coating.

Design - Irregular shape with sharply varying cross sections, and butt end filled with Urethane foam.

Quantity - Production problem, inspections at manufacture, production rate approximately 6 per hour per mold.

Characteristics to Evaluate - Production line inspection to evaluate part quality, voids, fiber distribution, resin segregation, bonding, uniformity and mechanical strength.

Magnitude of Quality Characteristics - Require minimum strength characteristics. Probably NDT would cover uniformity of the molded part and completeness of bonding, in conjunction with precise visual inspection.

Basis - Unacceptable part causes failure of weapon involving possible loss of personnel. Utmost reliability required.

Urgency - Required for immediate production use.

Redesign - Present mat and premix design may eventually change to all-premix design. The problem might then be eased with reference to homogeneity but only to moderate degree.

Present Inspection - Specially designed impact tester plus service test sampling. The impact tester is new and untested as yet. Correlation is with a destructive service test.

Limitations of Test Equipment - Equipment need not be portable or be otherwise limited. Should not be difficult to handle or slow.

Suggested Solution to
PROBLEM NO. 5

M14 RIFLE FIBERGLAS-REINFORCED PLASTIC STOCKS

Prepared By - B. C. Gerke

1. Mr. Szanto presented the problem in detail with exceptional clarity utilizing slides as an aid in presenting the problem. In addition, a sectionalized rifle stock and two molded halves were presented to the conferees for visual review and to provide better "feel" for the current problem.

2. The response from the floor indicated an overall interest in the problem.

3. The proposed areas of resolution can be reduced to the tests relating to end item acceptance, i.e., a substitute for the grenade firing tests. In this connection, it was recommended that consideration be given to the following approaches:

a. Mr. E. W. McKelvey, Wright-Patterson Air Force Base, suggested applications of X-ray radiography utilizing techniques which will differentiate fiber distribution in the molding processes. This is considered to be an extremely valuable suggestion and Mr. McKelvey will be contacted by Mr. Szanto for further details regarding his experiences in this field of endeavor.

b. Mr. S. D. Hart, NRL, suggested the techniques and approaches utilized by Dr. McMasters of Ohio State, employed in his recent study of fiber and resin distribution be investigated. This Mr. Szanto will do.

c. Dr. Tung-Ming Lee, Cold Weather Regions Research Engineering Laboratory, Hanover, New Hampshire, suggested a proposed approach to check control of requirements of materials as a "theoretical" approach prior to actual processing.

4. Several other suggestions were proposed, however, it was felt that the most important contributions were in the fields of X-ray radiography in which Mr. Szanto indicated further effort will be applied by Springfield Armory in developing data necessary to better understand the distribution and differentiation of fibers and resins in the molding process.

5. The best approach it appears is to assure that a satisfactory molded part is manufactured, then the subsequent end item performance of the assembled components will perform as expected.

6. In this connection it was recommended that In-Process Inspection controls be maintained, and a review of the finished molded parts be accomplished by means of fluoroscopy to assure appropriate distribution of fibers and resins.

7. Final end item testing for twist, and impact etc., should be continued until such time as sufficient historical data on quality and reliability performance are developed.

PROBLEM NO. 6

SUBSTITUTION OF NONDESTRUCTIVE
TEST METHOD FOR MERCUROUS NITRATE TEST OF BRASS CARTRIDGE CASES

SUBMITTED BY

NAVAL AMMUNITION DEPOT, OAHU, HAWAII

Presented By - David Hale

Statement of Problem

Determination of a Nondestructive Test method or methods suitable for replacing the currently used Mercurous Nitrate test for surveillance of brass cartridge cases.

Reason New Test is Needed

It has been recognized that the Mercurous Nitrate test may not be really applicable for ammunition which is to be fired soon after testing. Such testing may result in discarding thousands of dollars worth of ammunition which may actually still be serviceable. Furthermore, as the Mercurous Nitrate test is destructive in nature a real correlation of test results with actual firing results is impossible.

Background Information - from the conference at the Naval Weapons Station, Seal Beach, California - 9-12 Jan 1962.

"Stress corrosion cracking is the spontaneous failure of metals by cracking under the combined action of corrosion and stress. The Mercurous Nitrate Strain Test is conducted for the purpose of detecting in copper brass alloys the presence of residual (internal) stresses that might bring about failure of the material in service or storage through stress corrosion cracking. This test has found wide application throughout the brass products industries and has been used by the military services for many years as a criterion for acceptability of a manufacturer's production of brass cartridge cases. The Navy has, in addition, adopted the Mercurous Nitrate Strain Test for use in its periodic surveillance investigations to indicate susceptibility of Navy-held cases to stress-corrosion cracking, and thus to determine their suitability for continued use by the Fleet. The value of the test as a means of disclosing excessive levels of residual stress in fabricated brass products is widely accepted. It is also widely accepted that products offered by a manufacturer for Government use, in particular, brass cartridge cases, should be free of excessive stresses. This is indicated by making passage of the test a condition of purchase. However, from time to time questions have been raised concerning the importance of the test in the continuing surveillance of cartridge cases already bought and paid for. The philosophy underlying surveillance testing, as applied in the Naval Establishment, is that by use of appropriate

tests good ammunition can be separated from that which can no longer perform its design functions or which in use or storage will constitute an unacceptable risk of failure or hazard to personnel and equipment."

Suggested Approaches

Discussions at the Oahu Quality Evaluation Laboratory over the past few years have generally concluded that the problem might be best broken down into two major objectives:

First, selection of a test to determine whether actual cracks exist at the time of testing. A cartridge case containing actual cracks, particularly in the base area, would certainly be unsafe to fire.

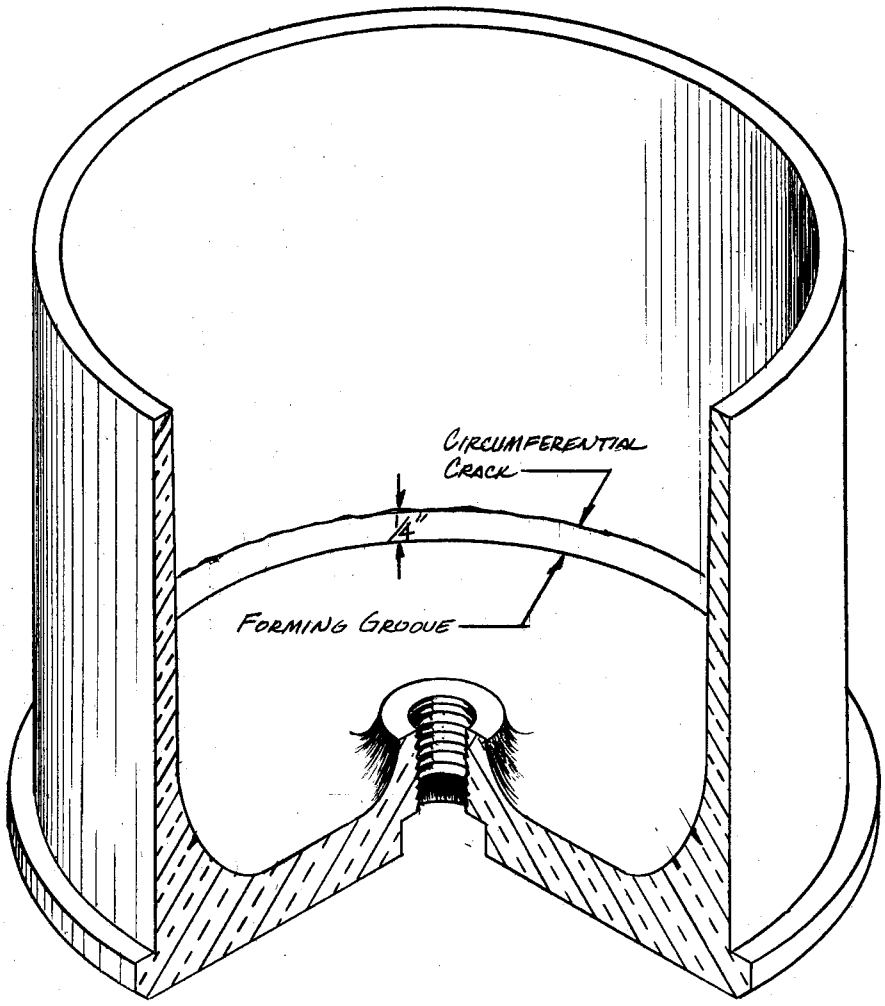
Second, determination of a Nondestructive test which would detect high levels of unrelieved stresses - stresses which would probably cause cracking after extended storage and exposure to a corrosive atmosphere. The test must be Nondestructive to enable correlation with actual firing results. The Mercurous Nitrate test mentioned previously is a fairly well accepted means of detecting residual stresses in brass cartridge cases, but it is destructive in nature and impossible to correlate directly either with cases to be fired immediately or after an extended period of storage.

Suggested Nondestructive Tests

Although little actual work has been done at the Oahu QE Lab, discussions within the Laboratory and with various consultants have indicated certain areas which may be promising. For the first test objective, that of finding cases actually containing cracks, the use of some type of visible dye or fluorescent penetrant has been suggested. This could detect any open-to-the surface crack or defect present. For the second objective of finding cases containing high internal stresses several methods have been suggested. Eddy current equipment is said to be sensitive to highly stressed areas within a material, although we are not aware of any commercially available equipment designed for this particular problem. Early tests at this Laboratory (although largely inconclusive) seemed to indicate that ultrasonic attenuation tests might vary with internal stress levels, as test results showed variations in attenuation that were independent of specimen geometry. A variation of this attenuation method was suggested by Professor Rohn Truell of Brown University. This involves enclosing the cartridge case in a chamber and measuring the attenuation or attenuation changes with the case under high internal pressure, or even under varying pressures.

A recent publication by Fred Rollins of the Midwest Research Institute suggests that with pulse-echo ultrasonics, highly stressed areas may be detected by shear wave birefringence--that is, the variation in velocity of shear waves with induced stress levels. Although the equipment and techniques used are probably a long way from field test techniques, this phenomenon may also prove useful.

PENETRATION - 25%



DEFECTIVE 5"/38 CARTRIDGE CASE

AMMO. LOT NO. BIR-10-MI-54

CASE LOT NO. 408 ITEM NO. 473 DATE OF TEST 5-10-62

MANUFACTURER FSC

DATE OF MANUFACTURE 5-1945

ONE (1) 360° CIRCUMFERENTIAL CRACK, 1/4" ABOVE FORMING GROOVE. INSIDE OF CASE.

FIGURE 1. CRITICALLY CRACKED CARTRIDGE CASE.

Open Discussion

These are only some ideas presented to start the ball rolling. Does anyone present have any comments on these ideas, or have any other comments or ideas which might apply to the entire problem?

DISCUSSION AND SOLUTION PROPOSALS
PROBLEM NO. 6

SUBSTITUTION OF NONDESTRUCTIVE
TEST METHOD FOR MERCUROUS NITRATE TEST OF BRASS CARTRIDGE CASES

Prepared By - S. Goldspiel
Presented By - David Hale

The following information was elicited during the presentation, which was not contained in the problem summary but was considered important in solution in the opinion of the conferees:

Regarding the Current Method

The mercurous nitrate test is destructive in nature, can be economically applied only to a small sample per lot, takes about three days to perform, involves problems of toxicity accompanying the use of mercury compounds and elaborate equipment to handle nitric acid and other "messy" solutions.

The indications obtained with the test are difficult to interpret and often controversial in nature.

Regarding Items Under Test

Geometry - Basically the items are cylindrical in shape and have flanges and internal grooves which are produced by cold forming.

Numbers - These run into thousands and vary with caliber of shells.

Sizes - Various sizes are involved, depending on the caliber. The section thicknesses vary appreciably for a case of a particular shell caliber as well as for cases of different shell calibers.

Condition of Test - The test may be performed on the disassembled case, especially during original manufacture and overhaul, but would be most desirable in the assembled form.

Aging - The test is to be performed during the course of manufacture after the usual stress relief (at about 475°F for a time depending on the section thicknesses involved); after shelf aging under variable conditions of environment and time of storage; and after straightening as during maintenance and reloading.

Stress in Test Components - Stresses within a case vary and have not actually been evaluated quantitatively. They are associated with incomplete relieving of forming stresses at fillets and grooves produced during original manufacturing and produced by straightening operations in the course of overhauling prior to refill. Hardness measurements do not clearly correlate with observed season cracking. For each particular shell case

there are readily determinable areas of greatest probable stress concentration, which might be considered, if it is desired to limit extent of nondestructive testing for purposes of speed and economy.

Form in Which Test is to be Applied - Tests may be conducted either on the OD, ID, or both depending on assurance quality level decided upon for a particular sampling plan selected.

SOLUTIONS AND COMMENTS OFFERED

The most feasible approach to the solution of the problem is to be sought in the use of Eddy Current type of nondestructive test. Under controlled conditions suitable equipment should be able to locate OD and ID flaws and locally overstressed areas in cartridge brass cases. Similar equipment has been developed[1] and used[2] in the past successfully to inspect fully loaded electrically primed 20mm high explosive shell bodies. In the particular application the following basic principle is employed. The probe utilizes two differential detecting coils, which are located at right angles to each other in order to be able to detect indications in all directions regardless of direction of traverse. The specimen traverse with relation to the search probe discriminates local areas of excessive stress or unsoundness compared to adjacent portions within the case. The null nature of the test eliminates irrelevant confounding indications which could otherwise be caused by differences in chemistry or metallographic structure as affected by mass, working, etc. Localized relevant areas of higher than average stress or containing undesirable unsoundness (cracks, voids, etc.) are indicated visually on an oscillograph, magic eye (preset to show a tolerable limit) or produce a reading on a voltmeter. It is possible to have a strip chart readout system which is correlated with the exact area on the specimen when suitable coordinating or synchronizing devices are built-in. Additional details on the equipment, method, approach, etc. to development of workable apparatus for the particular application, and assistance in general can be obtained[3].

An approach which might be useful to study the stress changes within cartridge cases as a function of time and during refabrication involves photostress coatings. The coating would be applied to the surface in the course of manufacture or early stages of inspection. Monitoring of the appearance of the birefringent coating under polarized light could be used to give data relating the location and change in stress distribution. The photostress technique would be of primary interest in analytical tests to correlate stress changes with destructive methods. In the latter case coupons deliberately stressed externally to known levels of various types of loading (compression, tension, torsion, etc.) could serve to develop judgments needed in evaluation of nondestructive test indications.[4]

A ballistic simulator for cartridge case loading which might serve in the nature of a prototype proof test is available[5]. It was indicated that the device was developed as a result of a need outlined during the 3rd DOD Conference on NDT at the Naval Gun Factory. The ballistic simulator generates upward of 70,000 psi pressure loading within 5 to 7 millisecond. It has been correlated to ballistic firing results and is used in the production acceptance of brass and steel cartridge cases for 75, 90 and 105 mm cases. Operating procedures, ordnance drawings, brochures and general information are available[5]. The writer of this report considers the use of the simulator applicable only as an intermediate between destructive and nondestructive tests, valuable principally for monitoring and general information purposes.

Should information be desired on correlations of mercurous nitrate test indications prior to perfection of a suitable NDT method, a contact has been suggested.(6)

General information relating to nondestructive as well as destructive methods for assessment of residual stress in metals may be obtained from a contact in a particular arsenal.(7)

This report has been prepared by the Problem Coordinator with the assistance and concurrence of the following:

B. C. Gerke, Army Weapons Command, Rock Island Arsenal, Illinois
S. D. Hart, U. S. Naval Research Laboratory, Washington 25, D. C.
C. A. Martin, Defense Supply Agency, Washington, D. C.
E. W. McKelvey, Wright-Patterson Air Force Base, Dayton, Ohio
J. W. Orner, Watertown Arsenal, Watertown, Massachusetts
E. Roffman, Frankford Arsenal, Philadelphia, Pennsylvania

REFERENCES

(1) Mr. Eugene Roffman, SMUFA-1120, Head Engineering Laboratory Branch, Mechanical & Electrical Inspection Equipment Division, Frankford Arsenal, Philadelphia 37, Pa.
(2) W. L. Smith, Lake City Ordnance Plant, Independence, Missouri
(3) See reference (1)
(4) Mr. D. J. Molella, Picatinny Arsenal, Dover, N. J.
(5) Mr. W. Inglis, Frankford Arsenal, Philadelphia, Pa.
(6) See reference (5)
(7) Mr. Harold Marcus, Chief, Metallurgy Laboratory, CC 1320, 64 Bldg. R&D Group, Pitman Dunn Labs, Frankford Arsenal, Philadelphia 37, Pa.

OTHER PROBLEMS SUBMITTED TO THE THIRTEENTH DEFENSE CONFERENCE ON NONDESTRUCTIVE TESTING

The following problems, not included in the regular agenda, were presented for consideration.

AGENCY	PROBLEM
Picatinny Arsenal Dover, New Jersey (Presented by D. J. Molella)	Inspection of brazed joints in 105 MM HE shells for proper bonding and fill.
Frankford Arsenal Philadelphia, Pennsylvania (Presented by W. W. Inglis)	Detection of defects in a tungsten alloy nose.

The following problems were not presented at the conference; however, conferees with an interest in any of the problems were urged to contact the contributing organization or the technical chairman.

AGENCY	PROBLEM
Army Engineers Research & Development Laboratory, Fort Belvoir, Virginia	Model 4A032, 6 HP Military Standard Engine Crankcase. The aluminum crankcase is diecast by the cold chamber process.
Norfolk Naval Shipyard Portsmouth, Virginia	Materials, equipment and techniques for obtaining 2-2T penetrameter sensitivity in pipe welds when they are radiographed under the requirements of MIL-STD-271B and NAVSHIPS 250-1500-1.
	Equipment and techniques for determining the wall thickness of badly pitted piping by ultrasonic methods.
	A practical method for determining the adherence of poured babbitt metal in dovetailed bearing shells.
Oklahoma City Air Materiel Area Tinker Air Force Base, Oklahoma	Quantitative Determination of Cleanliness of Hydraulic Filters.
Picatinny Arsenal Dover, New Jersey	Plating Thickness determination that is compatible with the plating specification requirements.
Quartermaster Research & Engineering Command, Natick, Massachusetts	Inspection of Leather Work Gloves for Stretch Requirement
Middletown Air Materiel Area, Middletown, Pennsylvania	Evaluation of corrosion in spar tubes of helicopter rotor blades.

TECHNICAL PAPERS PRESENTED AT THE
13TH DOD NDT CONFERENCE

NICKEL-63 TAGGED ELECTROLESS DEPOSITS APPLIED TO THE STUDY OF FILM COATINGS

NEW YORK NAVAL SHIPYARD

By

Solomon Goldspiel, Irving Canner, José Ordonez

ABSTRACT

This is a report of a preliminary investigation of the applicability of radioactive isotope-tagged substrate films, using Ni-63 in electroless deposited nickel, to the evaluation and solution of problems associated with protective coatings. Based on work with plain carbon steel test coupons with a substrate of electroless nickel tagged with Ni-63, results are shown which relate both the attenuated Ni-63 beta radiation and autoradiograph film density to chromium overlay thickness. Further applicability of autoradiography to visual interpretation of defects and continuity in overlay coatings is shown in nine autoradiographs representing the effects of grading overlay thicknesses and various artificially produced subsurface discontinuities in Cr, Cu and Au overlays. The overlay thickness limitation with Ni-63 as a tracer is about 0.14 mils of chromium, or the equivalent absorbing thickness of other material, when counting instrumentation is used, and slightly less with autoradiography. Eastman Kodak No-Screen X-Ray Film was used for all autoradiographs shown, principally for its speed. Several advantages of the use of autoradiography over other methods for the solution of problems involving protective films and coatings are noted.

BACKGROUND

Isotope tracer atoms in substrate films have the potential of providing information about overlay thickness, uniformity, continuity and defect content by enabling the measurement of attenuated radiation and/or the production of autoradiographs. In this preliminary investigation of the technique, Ni-63, tagged electroless deposited nickel, was chosen for the study because (a) the isotope has a half life of 85 years, (b) the 0.067 Mev beta radiation emitted by it is harmless, (c) it is readily available and inexpensive, and (d) ordinary nickel is widely used in plating practice both as a substrate and as a finished coating. In addition, electroless nickel can be deposited over non-metals as well as metals in almost any desired location, regardless of size or complexity of object. The tracer technique is of particular interest because, if successful, it suggests possibilities of monitoring coatings on engineering structures which have otherwise difficult accessibility when other methods are considered.

PROCEDURE AND RESULTS

Nickel Substrate[1] Thickness - One eighth inch thick carbon steel test coupons were used in this investigation, 1" diameter disc for the chromium overlay and 1" x 2" plates for the gold and copper overlay studies. Each specimen has a nickel substrate of 0.6 mils as determined by X-ray spectroscopy and metallography. This value exceeds the empirically determined infinite thickness of 0.5 mils, since beyond it, the beta count rate showed no appreciable increase. Control of the substrate thickness is, of course, necessary to assure constancy of initial beta radiation from the substrate which in turn assures the reproducibility in attenuation measurements when overlays of various thicknesses are involved.

In the course of development of methods for the measurement of the nickel substrate thicknesses by X-ray spectrographic techniques, a variation involving the attenuation of iron K-beta radiation from the steel was developed. This yielded the relationship shown in Figure 1, which applies to the range up to about 1.5 mils of nickel. In the empirical derivation of this relationship, multiples of 0.00035" thick pure nickel foils were used. Final results of electroless plating thickness determinations were checked by metallographic sectioning methods.

Chromium Overlay Thickness - In nondestructive application of tagged substrates to the study of particular coatings, it is necessary to establish relationships between attenuated intensity and/or density of autoradiographs to coating thickness. The following relationships investigated in this connection for chromium are shown graphically in Figures 2 through 5:

a. Beta attenuation from Ni-63 vs. Cr plating time, Figure 2.

b. Intensity of Cr K-alpha vs. Cr plating time, Figure 3.

c. Plating time vs. Metallographic Cr thickness (microsection), Figure 4.

d. Beta attenuation from Ni-63 vs. Cr plating thickness, Figure 5.

In this work, relationship (d) was of primary interest, all others being used either to derive it, or to prove it.

It is clear from the graphs that both attenuation of beta from substrate Ni-63 and the intensity of fluorescent X-rays from Cr overlay can be related to the plating thickness of the Cr overlay. However, it must be emphasized that if the results of either are to agree with a small number of metallographic (micro-section) measurements, which is the primary method, it is essential that the coating be uniform in thickness throughout. This follows from the fact that the former methods involve radiations from considerable volumes of the specimen, whereas the metallographic method yields results for individual sections, and that for

[1] The details of the technique for depositing electroless nickel on the test coupons, are described in Appendix I.

any area the volume is proportional to the thickness only if the thickness remains constant. If the overlay thickness is not uniform, agreement between the two nondestructive methods and metallographic measurements can be achieved substantially only when a large number of sections are measured and the results suitably weighted in computation.

Of the two nondestructive methods, i.e. attenuation of beta counts from substrate and intensity of fluorescent X-rays from overlay, it is considered that the former is more universal in application, because it is less limited by problems of accessibility of available instrumentation and complexity of surface of object under study. It will be noted that about 0.14 mils is the limit of thickness to which the curve of Figure 5 is applicable, with the amounts of tracer and substrate used in this study. This provides an adequate range for numerous applications such as the use of electroplated Cr plating for corrosion protection. In addition, the equivalent thicknesses of other metals offer considerable potential, once the actual relationships for various overlays have been determined.

Autoradiographic Studies of Overlay Continuity - Having established the feasibility of using beta attenuation measurements from substrates to the study of Cr overlay thickness, an attempt was next made to explore the suitability of autoradiography to plating problems involving their continuity and uniformity. A set of five samples grading in Cr overlay thickness from 0 to 0.14 mils were autoradiographed using Kodak No-Screen X-Ray Film. A light tight wood cassette constructed in such a manner as to provide good contact between the film and specimen surface, by pressure with sponge rubber inserts, was used in this work. The autoradiographs, reproduced in Figure 6, show that each autoradiograph is substantially uniform in density except at the edges (where differences may be due to edge effects in deposition) and that the darkening of the areas decreases with overlay thickness up to 0.14 mils. The latter Cr thickness appears to be the limiting thickness beyond which darkening of the film is not obtained in a reasonable exposure time. A plot of autoradiograph film density vs. Cr overlay thickness is linear up to about 0.10 mils, as shown in Figure 7. Beyond this thickness the departure from linearity is attributable to the film response limitations. For the linear range of the curve, it is considered, however, that the discrimination is good and that further improvement might be achieved by exposure to higher base level beta activity.

Emulsions Used - Kodak Autoradiographic Types A and No-Screen emulsions were also tried in this work for comparison to the X-Ray No-Screen Film. The ultimate choice of the latter was based on its higher speed which permitted a greater number of trials within a given time although at a possible sacrifice of the advantages of the former two emulsions, such as resolving power and linearity of response.

The remaining experimental procedures were directed toward the exploration of autoradiography to the study of the continuity and structure of overlay coatings, since basically the method has potential advantages of

being applicable to the examination of surfaces even where limited accessibility and complexity make other known methods inapplicable and to disclosure of defects even below the surface of overlays.

Sensitivity - The sensitivity of autoradiographic technique utilizing Ni-63 beta substrate emissions is demonstrated in Figure 8, which shows a reproduction of autoradiographs of various artifacts placed over the substrate as noted therein. The sensitivity of Ni-63 tagged electroless nickel substrate in revealing overlays is forcefully demonstrated in Figure 9. Here, the sample was produced as follows. A steel coupon with tagged substrate was coated with paraffin. Artifacts were engraved in the paraffin to the base nickel with a fine point. The uncovered nickel was electroplated with copper from a cyanide bath and the paraffin mask was removed prior to autoradiography. Attention is invited to the density differences between many polygonal areas which corresponds to differences in overlay deposits.

Resolution - Photo (A) in Figure 10 shows a pattern obtained by placing a piece of nylon cloth between the substrate and film indicating the detail in resolution of overlays which the method is capable of discerning. Photo (B) of Figure 10 is a sample in which the overlay is 0.00004" of gold. The grid pattern was produced by placing a piece of 100 mesh wire cloth over a portion of the sample prior to the deposition of the overlap by vacuum vaporization.

Detection of Subsurface Discontinuities - Figure 11 shows an autoradiograph produced by the sample used in Figure 10B after it had received the following additional treatment. A part of the sample was protected with a cover-glass slide and more gold was vacuum-deposited over the remaining portion until the grid disappeared when viewed by naked eye. It will be noted that the portion with a double layer of gold clearly reveals the grid structure of the lower layer. This is interesting because it demonstrates that the method is capable of disclosing discontinuities below the actual surface of coatings, and suggests that such discontinuities in plating as interface porosity, lack of bonding and other interruptions in substrate layer continuity may be revealed by the method.

CONCLUSIONS

This study has demonstrated that radioisotope tagged electroless substrates, as represented by Ni-63 electroless nickel, may be used effectively in problems involving protective films and coatings in the following ways:

a. To study thickness changes of overlays of up to 0.14 mils of Cr or equivalent absorbing thicknesses of other overlay materials;

b. To study changes in continuity, with detail resolution estimated at 0.1 mm or better;

c. To study or disclose subsurface discontinuities such as interface porosity, dirt, lack of bond, etc.

d. By precoating structures with radioisotope tagged substrates, a method is provided whereby coatings and films can be studied for changes with time even on objects whose surface complexity and accessibility makes other methods applicable with difficulty or not at all.

ACKNOWLEDGMENT

Acknowledgment is made to Mr. M. L. Foster for his participation in the earlier work on this project, to Messrs. J. Kalinsky and C. LaRosa who contributed the work on plating and measurements involving radioisotope chemistry techniques, and the Messrs. E. Haas and F. Doria for their assistance with techniques for vacuum deposition of gold. Special acknowledgment is also made to Mr. E. A. Imbembo, Head of the Metallurgy Branch for his technical review of this work.

APPENDIX I

Description of Electroless Nickel Plating Technique

Radioactive Ni-63, as $NiCl_2$ in HCl solution, with a specific activity of 3.2 mc per ml., was used to prepare a stock solution containing 12.8 uc of Ni-63. A solution consisting of 100 lambda (0.1 ml.) of Ni-63 and 400 mg of $NiCl_2$-$6H_2O$ inert, as carrier, was diluted to 25 ml. with 0.01 N HCl. Eight Hundred lambda (0.8 ml.) of Ni-63 stock solution were added to the plating solution which was made up as follows:

20 ml. of 220g/l. nickel chloride ($NiCl_2$-$6H_2O$)

20 ml. of 300g/l. sodium hypophosphite (NaH_2PO_2-H_2O)

20 ml. of 100g/l. Versene "100" powder (tetrasodium salt of ethylenediamenetetraacetic acid)

10 ml. of 150g/l. sodium succinate ($Na_2C_4H_4$-$6H_2O$).

The solution was made up to 200 ml. with water in a 400 ml. beaker. The pH of the resulting solution was between five and six. Mild steel coupons one inch in diameter, which had been polished with 3/0 emery paper, cleaned by refluxing in petroleum ether, dipped in acetone and etched for two minutes in concentrated sulphuric acid (95%), were suspended in the bath and maintained at a temperature of 95-99°C with constant stirring. The coupons were placed in the bath so that the side to be plated faced toward the wall of the beaker. The coupons were kept in the bath for a period of three hours to give a plating thickness of at least 0.5 mil (0.5×10^{-3} inches). This value exceeded the infinite thickness value for the Ni-63 B emission and assured uniform counting with maximum self-absorption at the Ni surface. Approximately 10.24 μc of Ni-63 were added to the plating bath to assure a count rate greater than 10,000 counts per minute by Geiger windowless flow counting of the 0.067 Mev beta. Upon completion of the three hour plating period, the coupons were washed with water and dried with acetone and placed in a dessicator until ready for continued use.

No. OF NICKEL FOILS*	FOIL THICKNESS (MILS)	INTENSITY COUNTS/SECOND **	LOG OF INTENSITY
0	0.00	27,758	4.44
1	0.35	3,836	3.58
2	0.70	559	2.75
3	1.05	82	1.91

* Over carbon steel blanks

** Corrected for background

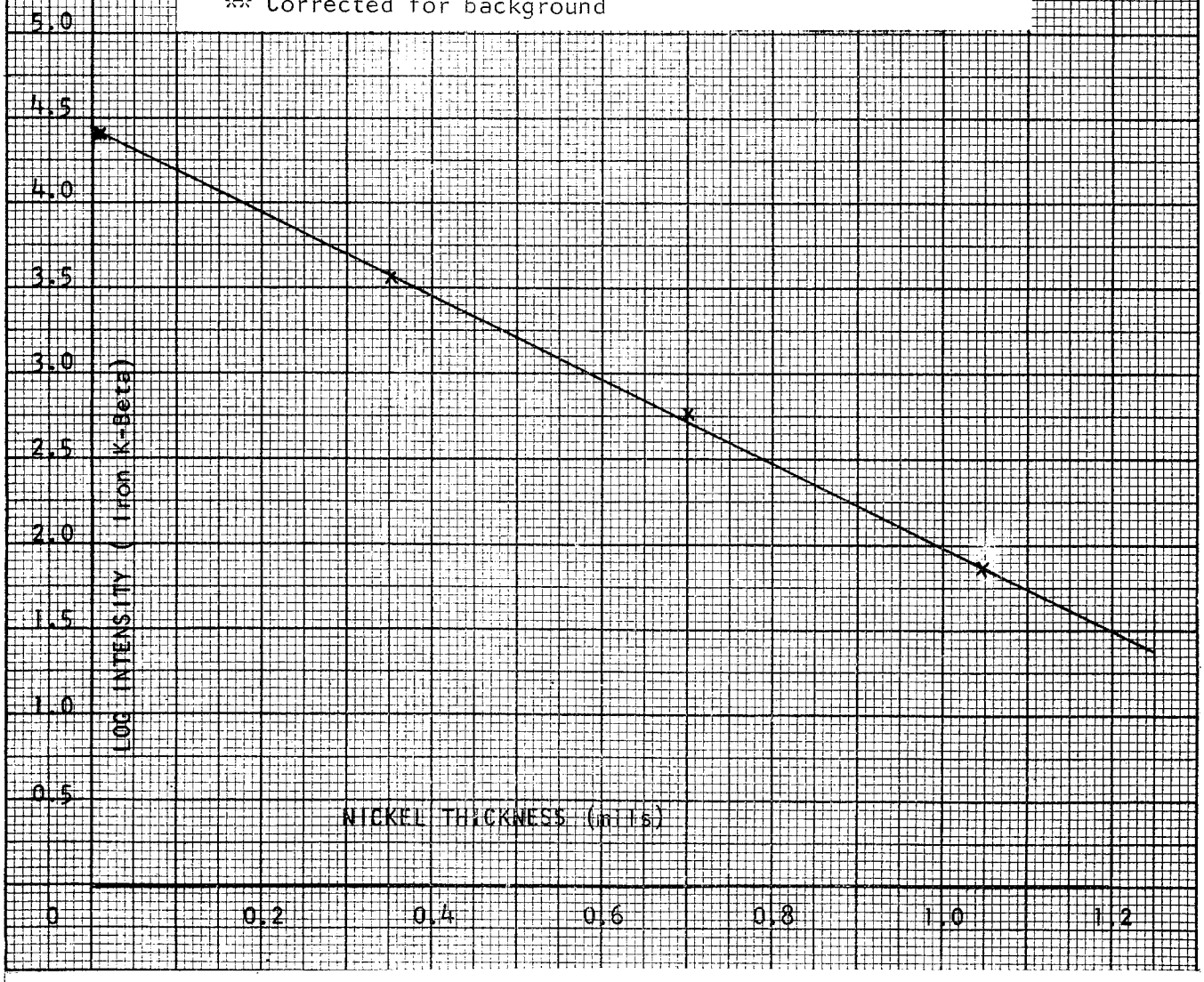


Figure 1. Calibration Curve
Nickel Thickness in Mils Vs. Log Intensity of Iron K-Beta

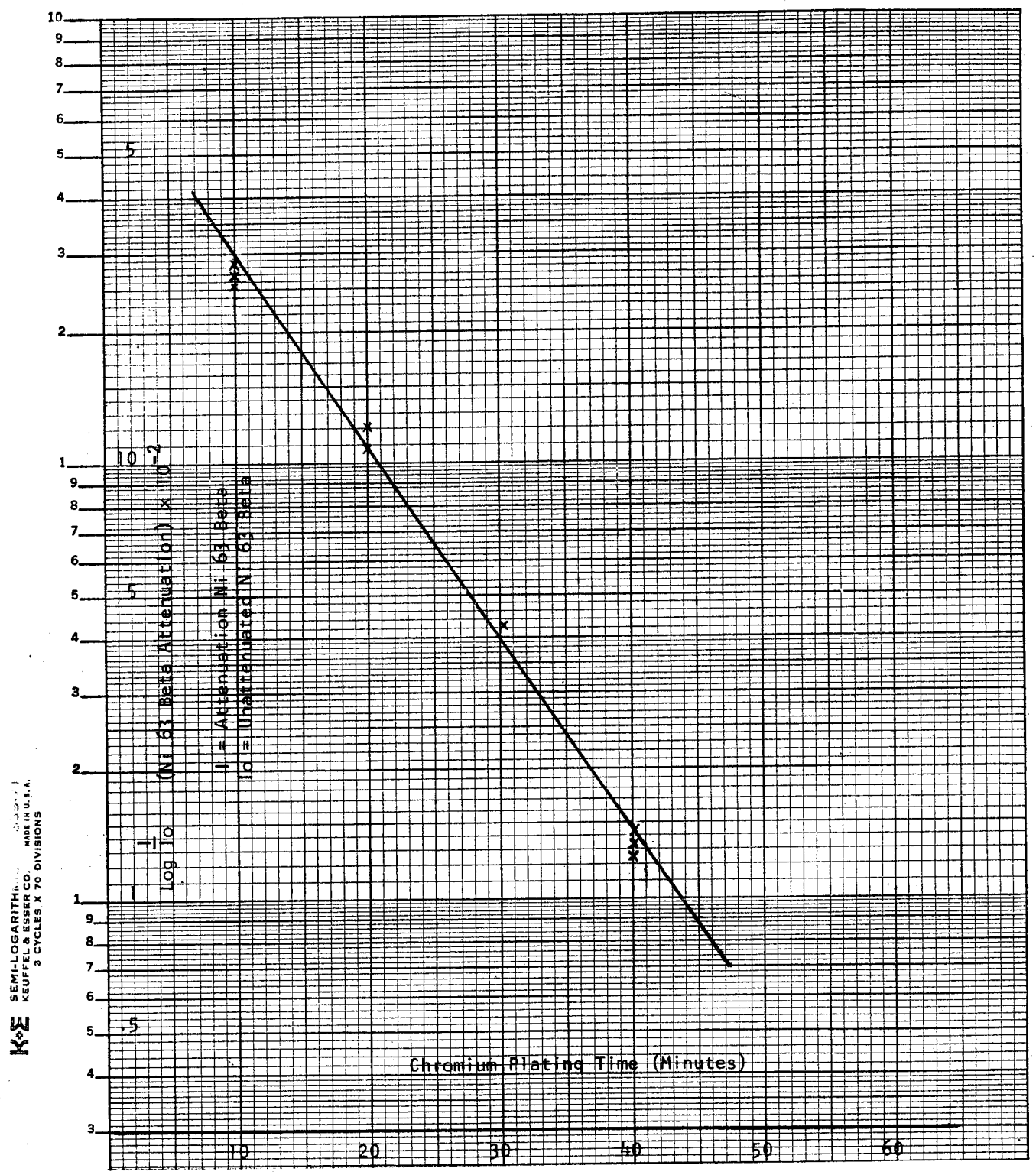


Figure 2.

Beta Attenuation of Ni-63 vs. Chromium Plating Time

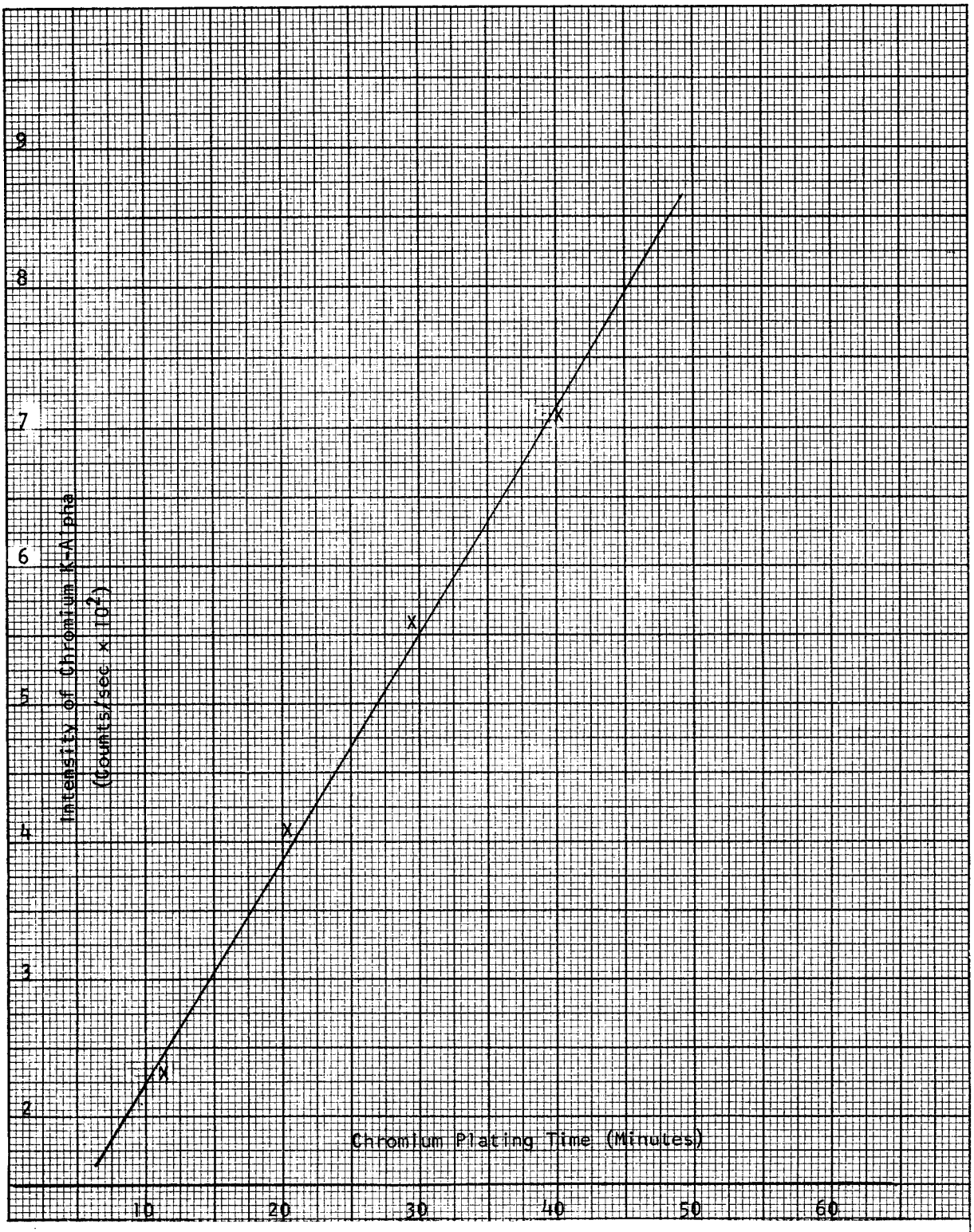


Figure 3.

Intensity of Chromium (K-Alpha) vs. Chromium Plating Time

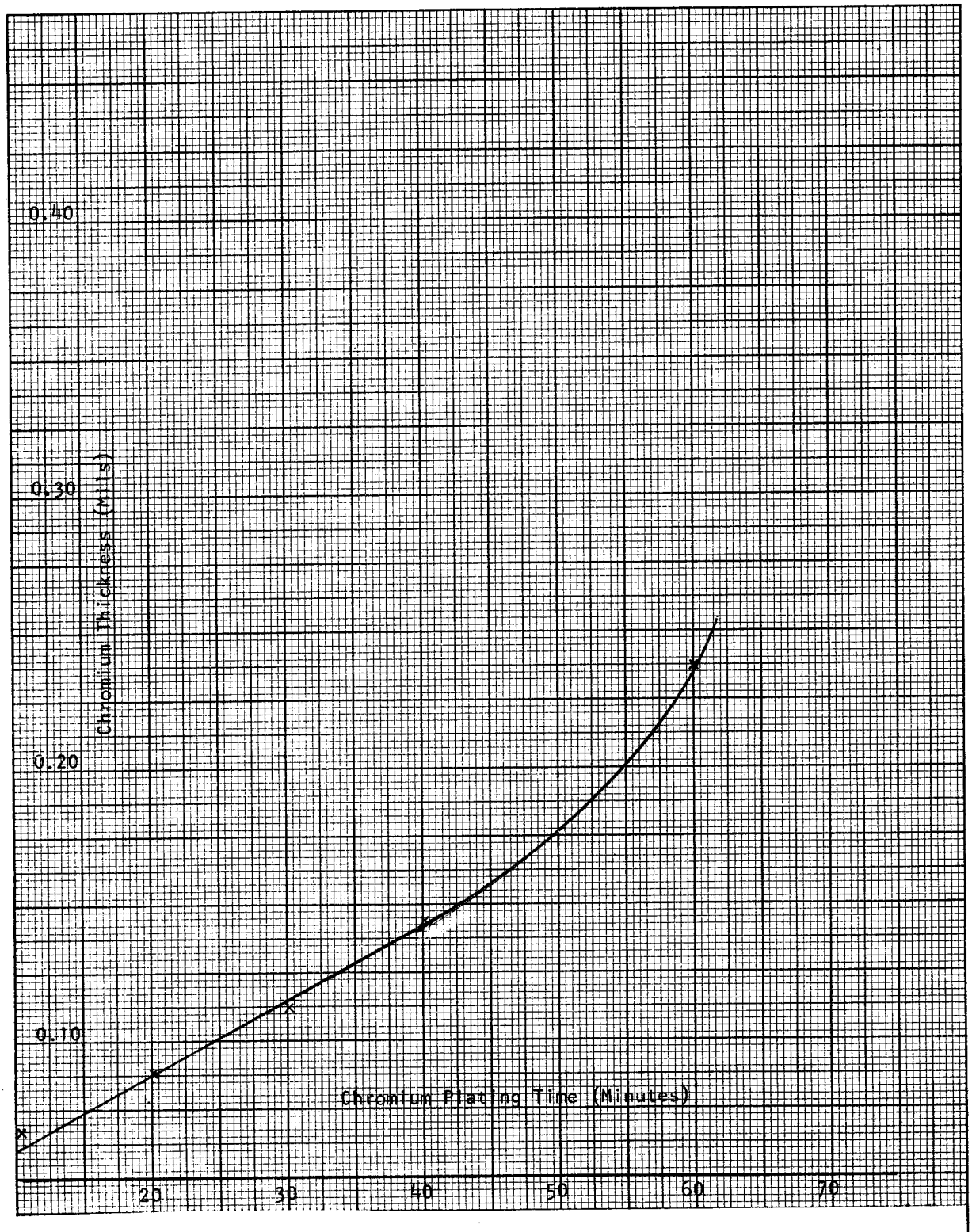


Figure 4.

Plating Time vs. Metallographic Chromium Thickness (micro sections)

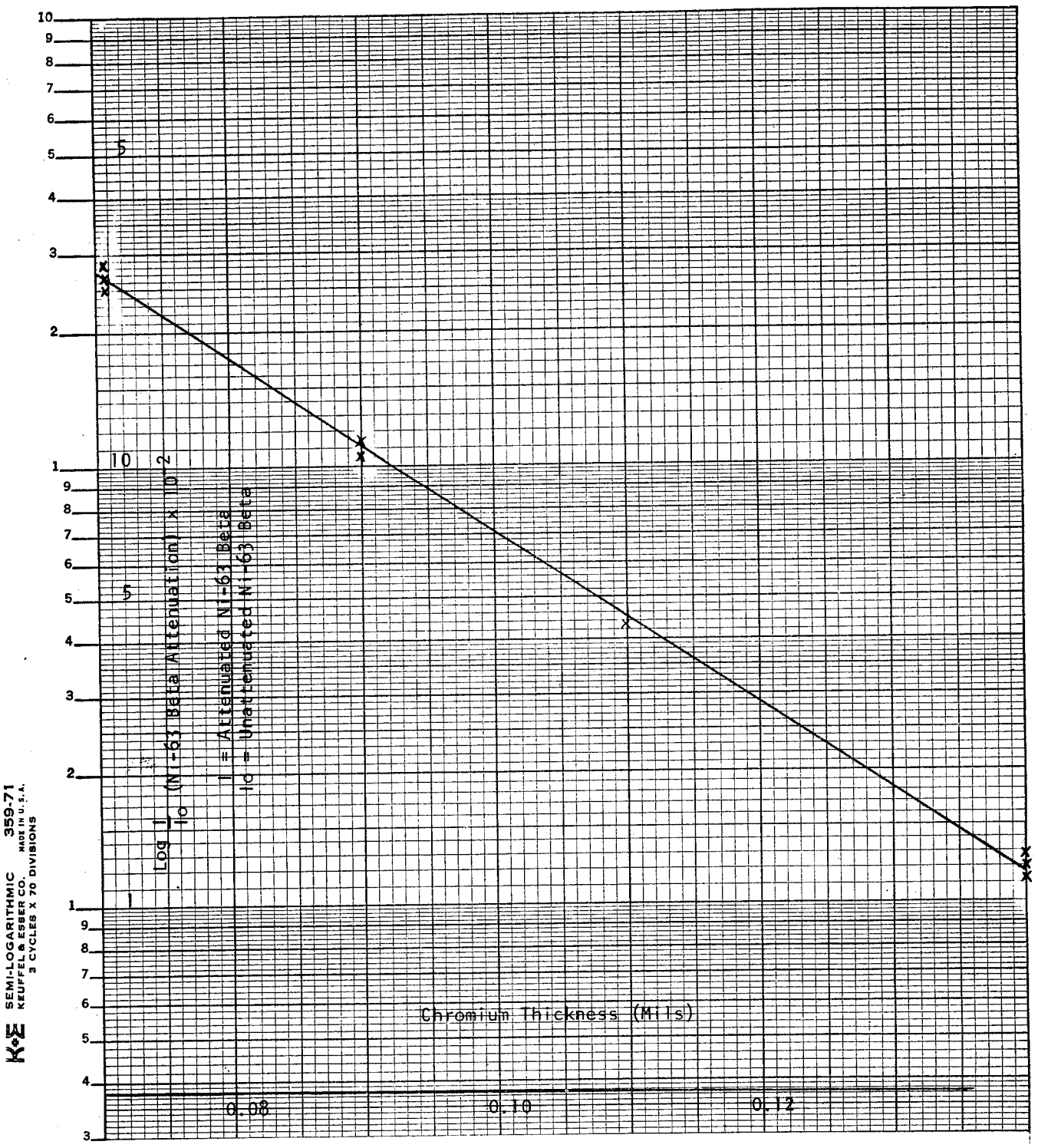
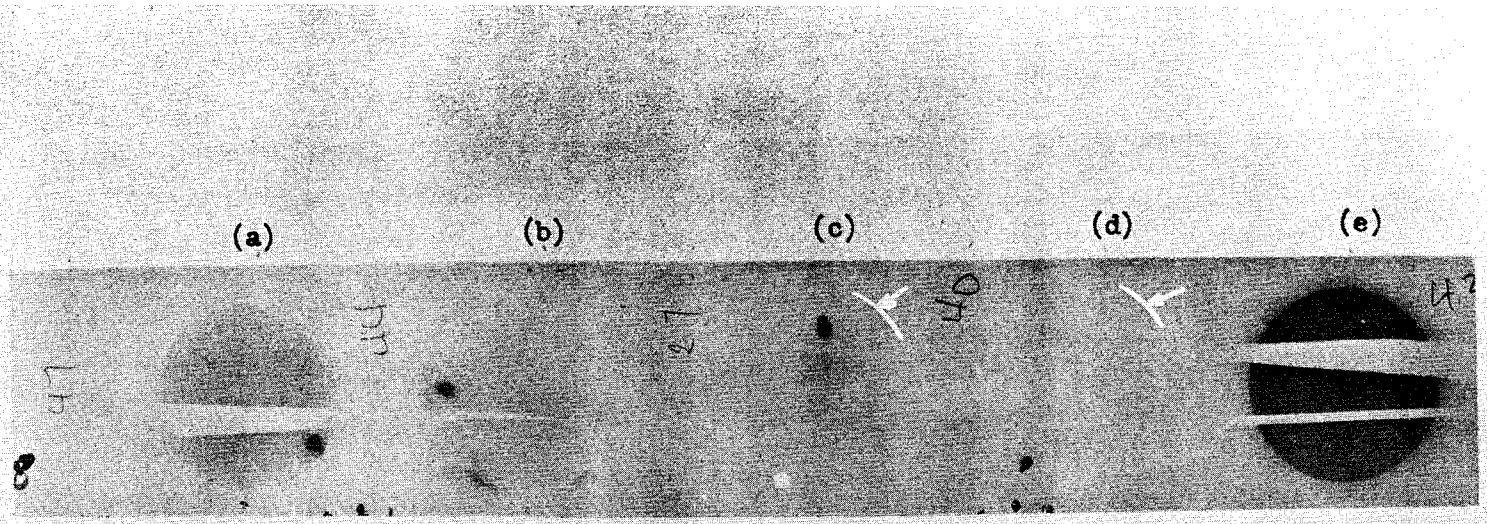


Figure 5.

Beta Attenuation of Ni-63 vs. Chromium Plating Thickness



Sensitivity of Autoradiographs Produced with Ni 63 Tagged Electroless Nickel Substrate, Grading in Cr Overlay Thickness, With Lead Strips Interposed Between Sample and Kodak No-Screen X-Ray Film. 96 Hours Exposure.

Cr Overlay Thickness (mils) : (a) 0.07 (b) 0.09 (c) 0.11 (d) 0.14 (e) no overlay

Photo No. L19093-1

FIGURE 6

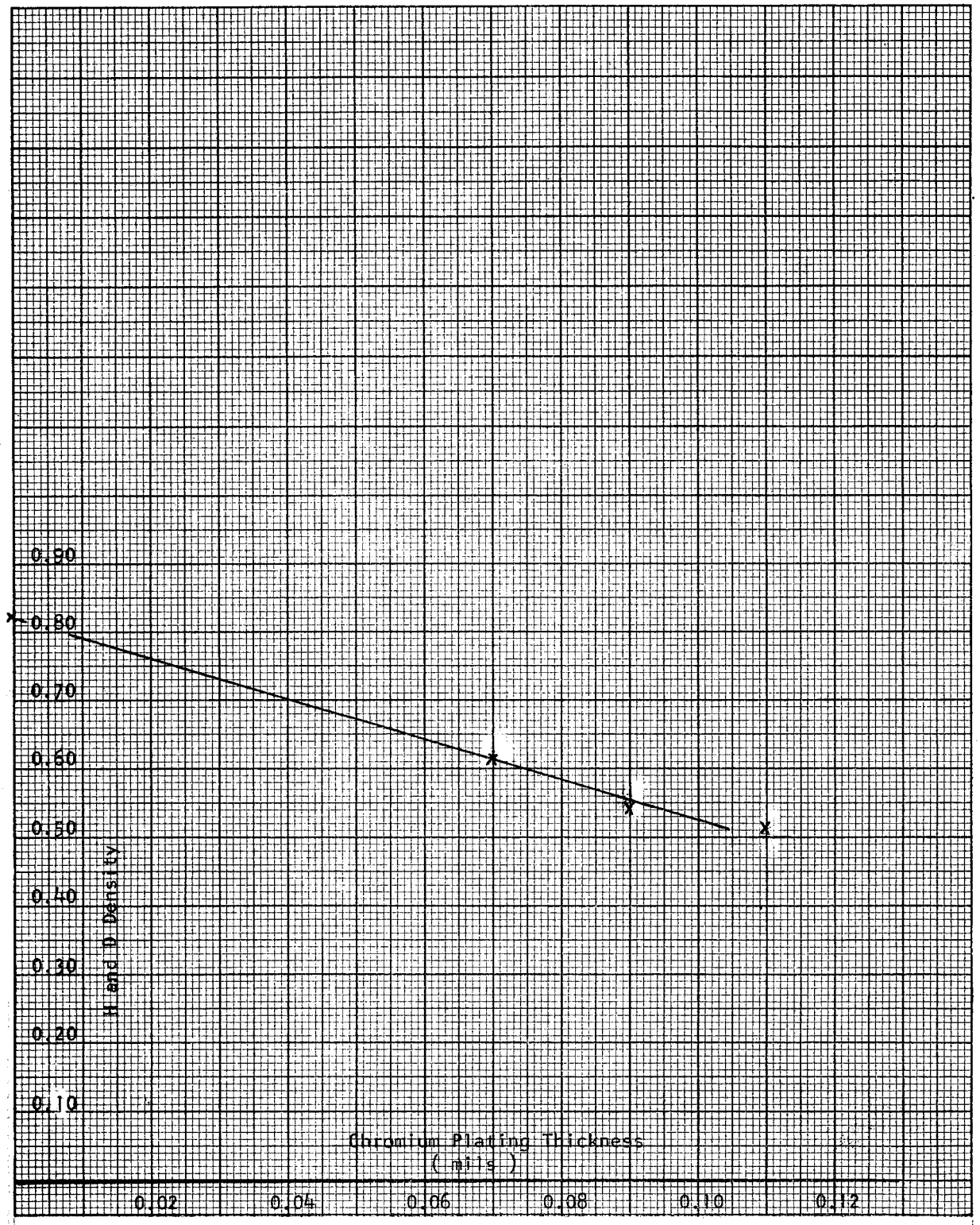
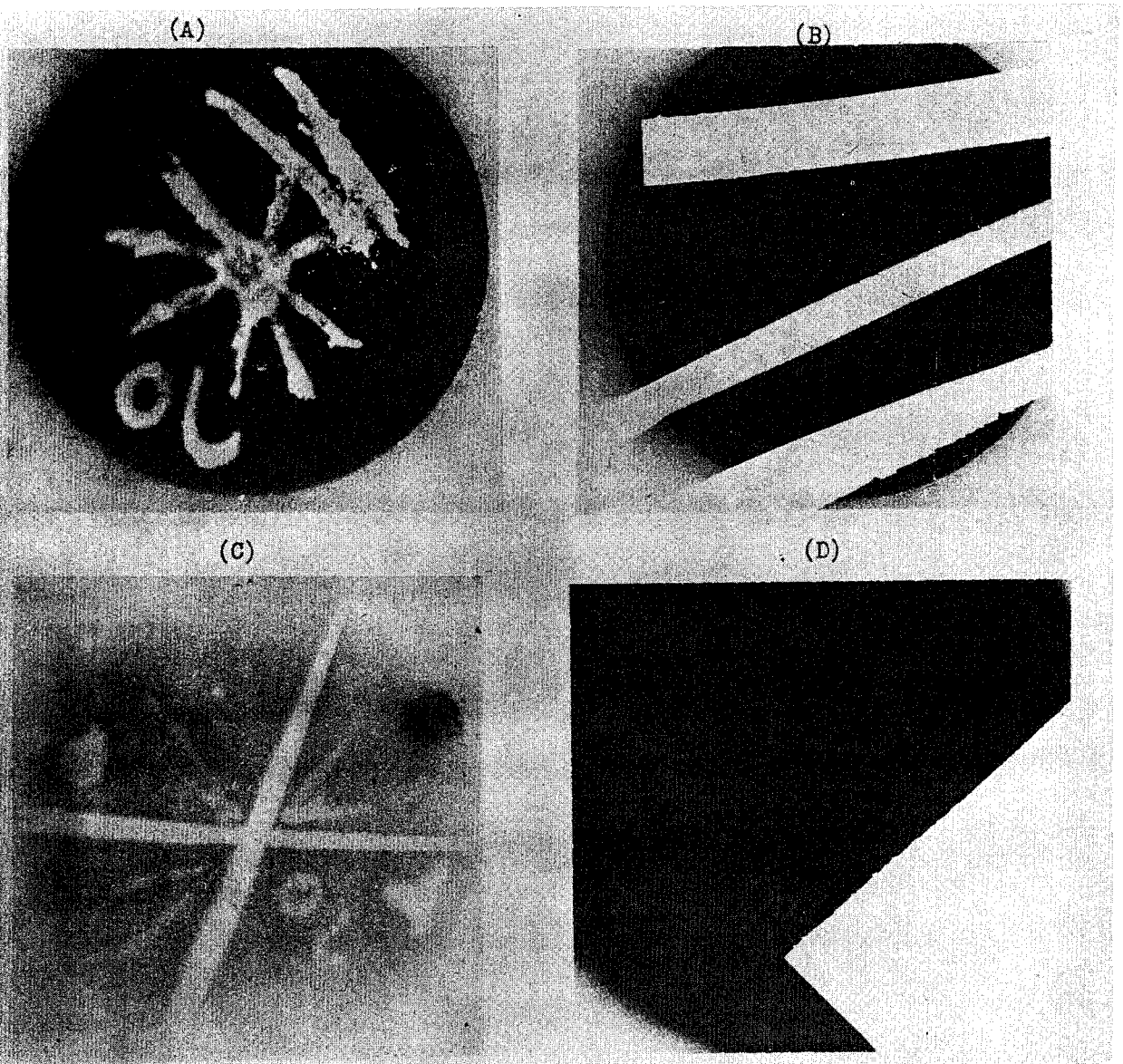


Figure 7.

Autoradiograph Density vs. Chromium Plating Thickness



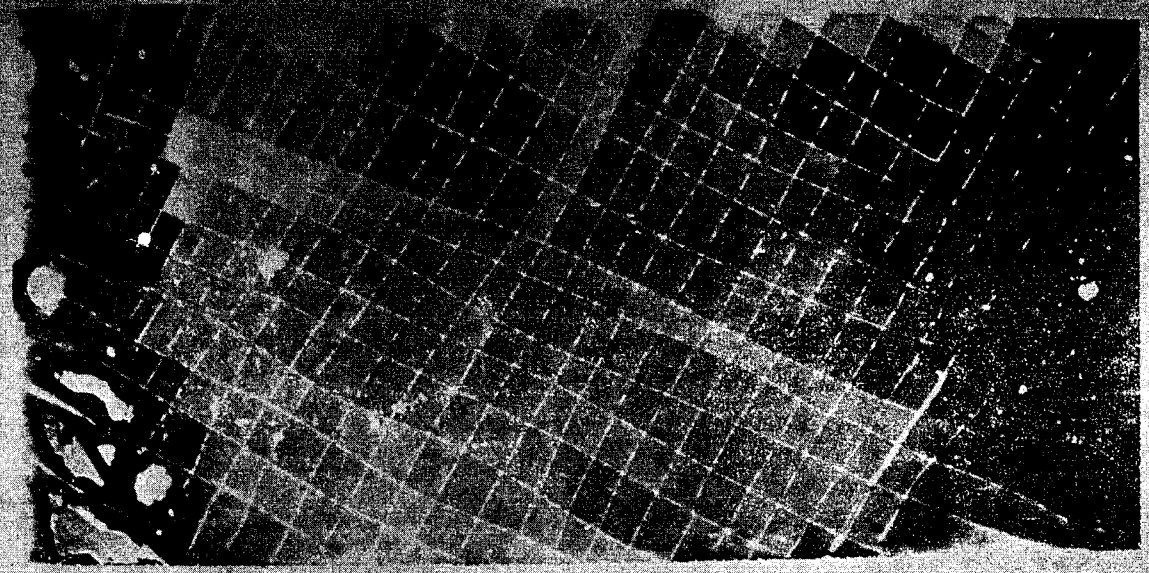
Sensitivity of Autoradiographs Produced With Ni-63 Tagged Electroless Nickel Substrate Exposed For 96 Hours On Kodak No-Screen Film (5X)

(A) Artifacts produced with India ink plus $Pb(NO_3)_2$ writing;
(B) Artifacts produced with 0.0005" gold foil (at top and bottom) and 0.0003" aluminum foil (at center);
(C) Artifacts produced over 0.07 mils Cr plating with Scotch tape (.002") and India ink writing;
(D) Absorption by 0.003" of paper.

For (A), (B) and (C) the tagged nickel plating bath produced a base count of 11,300 per minute; for (d) the concentration of Ni-63 was tripled.

Photo L 19093-2

FIGURE 8



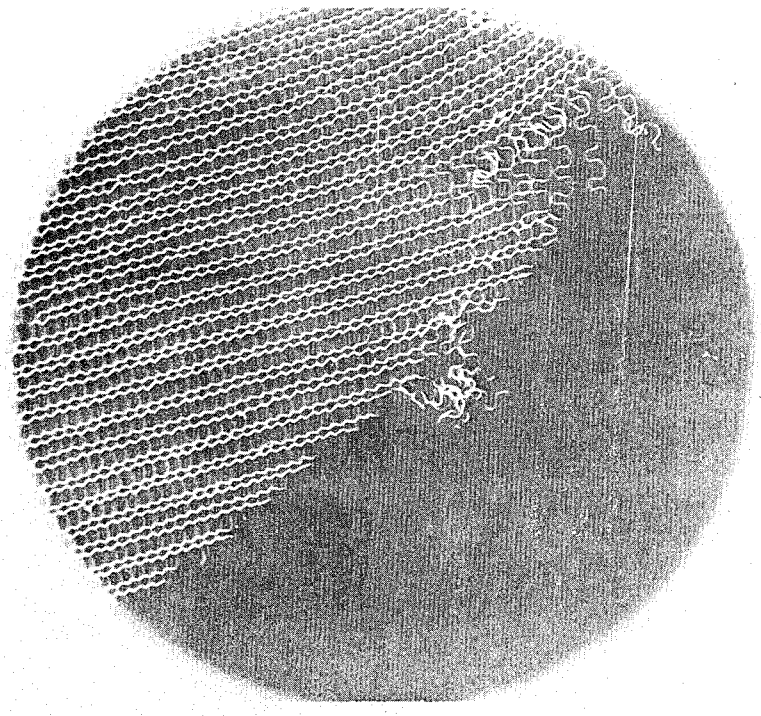
Sensitivity of Autoradiographs Produced with Ni-63 Tagged Electroless Nickel Substrate Exposed for 96 Hours on Kodak No-Screen Film. (5X)

Artifacts produced in a electrodeposited Copper overlay.

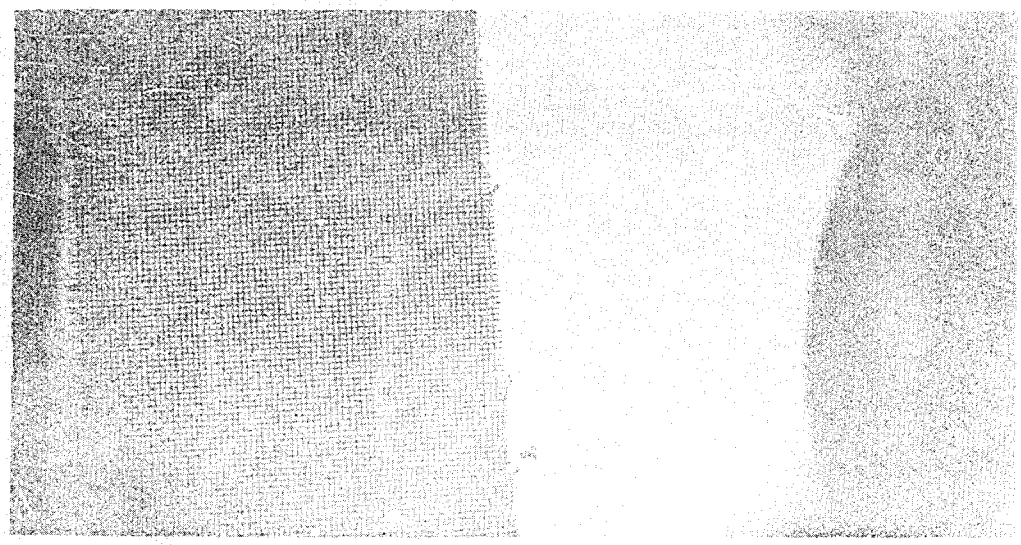
Photo L-19093-3

FIGURE 9

(A)



(B)

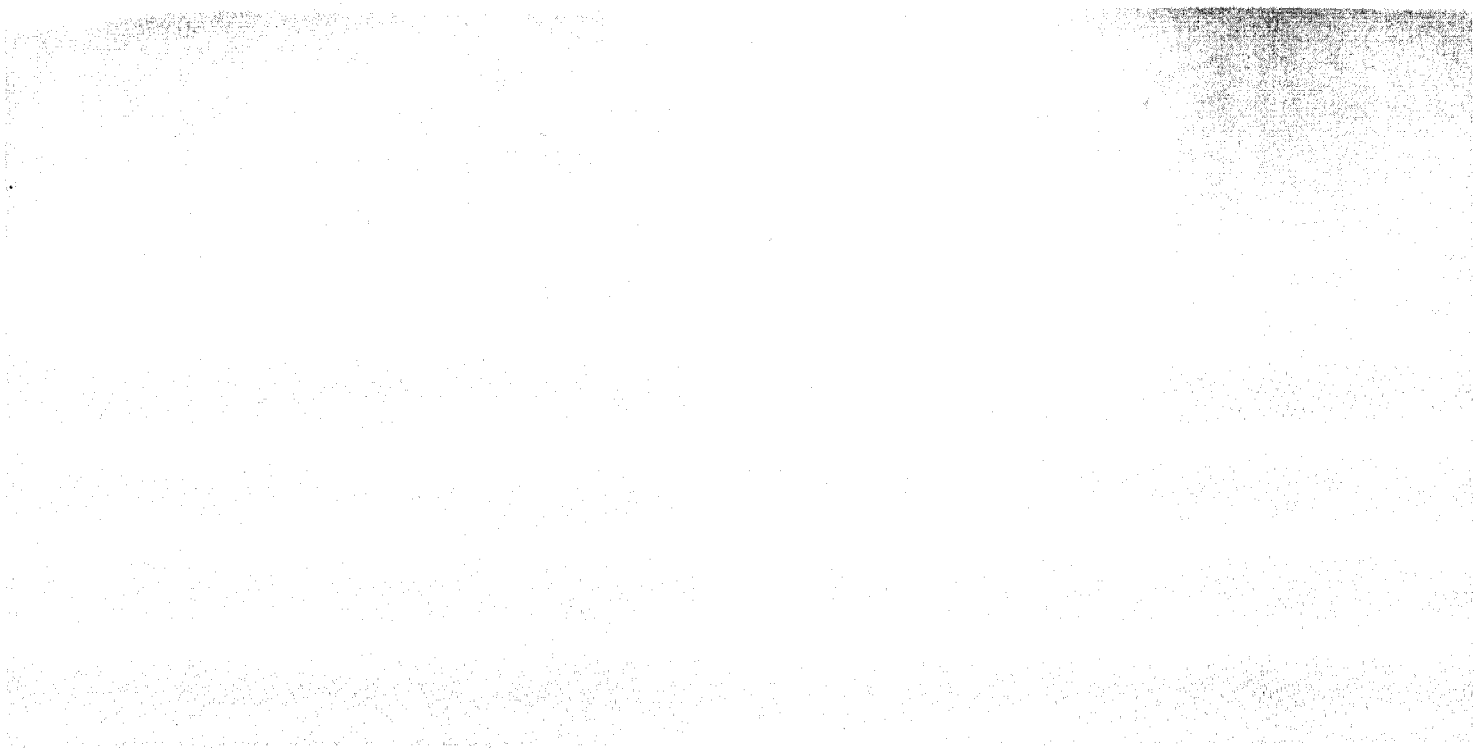


Reproduction of Autoradiographs Produced with Ni-63 Tagged Electroless Nickel Substrate Exposed for 96 Hours on Kodak No-Screen Film. (5X)

(A) Nylon cloth overlay.
(B) Vacuum deposited gold overlay through 200 mesh copper screen.

Photo L-79094-b

FIGURE 10



Subsurface Discontinuities Revealed by Autoradiography with Ni-63 Tagged Electroless Nickel Substrate Exposed for 96 Hours on Kodak No-Screen Film. (5X)

Upper left - double Au overlay, through mesh, followed by unobstructed overlay.
Lower left - single Au overlay through mesh.
Upper Right- double Au overlay, unobstructed.
Lower Right- single Au overlay, unobstructed.

Photo L-19093-5

FIGURE 11

METHOD OF DETERMINING DYNAMIC PROPERTIES OF VISCO-ELASTIC SOLIDS EMPLOYING FORCED VIBRATION

ARMY COLD REGIONS RESEARCH & ENGINEERING LABORATORY

By

Tung-Ming Lee

ABSTRACT

The technique of determining the dynamic properties of solids involving forced vibration has been pursued diligently since Quimby[1] first developed the idea in 1925. In general, it is the technique of employing a transducer cemented to a specimen and subsequently exciting the composite rod to the resonant frequency. Using the resonance criterion, the dynamic moduli of the sample can be determined from the measured resonant frequency and the physical dimensions of the composite rod.[2,3,4,5] Experimental errors[6] recognized in this method are introduced by cementing of the transducer to the specimen, the difference in cross-sectional area of the driving oscillator and the specimen, and the presence of lateral motion during the test. The main difficulty, however, arises from the nature of coupling the specimen to the driver and, consequently, from the accuracy of measurements pertaining to the physical properties of the vibrating unit, especially when a complex system of more than just one simple transducer is used.

To avoid the above mentioned difficulty due to coupling, a criterion using the maximum amplitude ratio, R_{max}, of the vibration amplitude at both ends of a sample and the corresponding vibration frequency, F_{ro}, is introduced. Simple expressions relating dynamic properties of a visco-elastic

solid to R_{max} and F_{ro} are obtained. Thus, when R_{max} and F_{ro} are measured from experiment, one may readily determine the dynamic properties of the sample.

Both the longitudinal vibration method and the torsional vibration method have been considered in the present work. Two basic models representing the constant driving-amplitude system and the constant induced-stress system are used in the longitudinal vibration study. A simple model of circular cylinder is assumed for the torsional vibration analysis. It is demonstrated that the same criterion can be applied in each case.

The study is based upon the theory of wave propagation. The complex modulus is used for convenience in describing the stress-strain relationship of a visco-elastic solid. And, also, it eliminates the necessity of assuming any model visco-elastic solid.

INTRODUCTION

The forced vibration technique of determining the dynamic properties of solids has been pursued diligently since Quimby[1] first developed the idea in 1925. In general, the technique involves cementing a transducer to a specimen and subsequently exciting the composite rod to the resonant frequency. Using the resonance criterion, the dynamic moduli of the sample can be determined from the measured resonant frequency and the physical dimensions of the composite rod.[2,3,4,5] Experimental errors[6] recognized in this method are introduced by cementing of the transducer to the specimen, the difference in cross-sectional area of the driving oscillator and the specimen, and the presence of lateral motion during the test. The main difficulty, however, arises from coupling the specimen to the driver and, consequently, the accuracy of the experiment is dependent upon that of the measurements pertaining to the physical properties of the vibrating unit, especially when a complex system of more than one simple transducer is used.

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1. S. L. Quimby, Phys. Rev. 25, 558 (1925).
2. L. Balamuth, Phys. Rev. 45, 715 (1934).
3. F. C. Rose, Phys. Rev. 49, 50 (1936).
4. N. B. Terry, Brit. J. App. Phys. 8, 270 (1957).
5. J. W. Marx and J. M. Sivertsen, J. App. Phys. 24, 81 (1953).
6. N. B. Terry and H. J. Woods, Brit. J. Appl. Phys. 6, 322 (1955).

To avoid the difficulty due to coupling, a criterion using the maximum amplitude ratio and the corresponding vibration frequency is introduced. And, as is shown, these measurements are sufficient to determine the dynamic properties of a solid.

Both the longitudinal vibration method and the torsional vibration method are considered in the present work. Two basic models representing the constant driving-amplitude system and the constant driving-force system are used in the longitudinal vibration study. A circular cylinder is assumed for the torsional vibration analysis. It is demonstrated that the same criterion can be applied in all the cases.

I. LONGITUDINAL VIBRATIONS, GENERAL CONSIDERATION

A. Formulation of the Solution

The equation of motion from a longitudinal disturbance along a thin filament is well-known:

$$\frac{\partial \sigma}{\partial z} = \rho \frac{\partial^2 u}{\partial t^2} \tag{1.1}$$

where σ and u are the stress and displacement, respectively, at distance z along the filament from the origin, and ρ is the density of the medium. While there is no simple relation available to express stress in terms of strain for a real viscoelastic solid[7], the fact that the strain ε in a linear viscoelastic solid varies sinusoidally as the stress σ but lags behind it by a loss angle δ can be used to express the relationship conveniently by the complex modulus:

$$\sigma = (E' + iE'')\varepsilon = (E' + iE'')\frac{\partial u}{\partial z} \tag{1.2}$$

where E' and E'' are the real and imaginary parts of the complex modulus "E". The ratio E''/E' is a measure of the energy dissipation and is generally denoted by the loss factor $\tan\delta$.

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7. H. Kolsky, International symposium on stress wave propagation in materials, Interscience Publishers, Inc., New York, 1960.

Hence, the longitudinal wave propagation equation for a linear visco-elastic solid subjected to a sinusoidal disturbance is obtained from substitution of (1.2) in (1.1)

$$(E' + iE'')\frac{\partial^2 u}{\partial z^2} = \rho \frac{\partial^2 u}{\partial t^2} \tag{1.3}$$

In applying the forced vibration technique for investigating the dynamic properties of a visco-elastic solid, (1.3) may be used to describe the wave propagation in the system if it undergoes harmonic motion. Consequently, the displacements in this type of problem may be expressed, from (1.3), in the following convenient form

$$u = \left[A \cos \gamma z + B \sin \gamma z \right] \cos \omega t \tag{1.4}$$

where A and B are the constants to be determined from boundary conditions and

$$\gamma = \left(1 - i \tan \frac{\delta}{2}\right)\frac{\omega}{C} \tag{1.5a}$$

C = the longitudinal phase velocity

$$= \left(\frac{E^*}{\rho}\right)^{1/2} \sec \frac{\delta}{2} \tag{1.5b}$$

$$E^* = \left(E'^2 + E''^2 \right)^{1/2} \qquad (1.5c)$$

and ω = the angular frequency of the oscillation.

B. Vibration Systems

To facilitate the analysis, we group the various vibration systems for this testing purpose into the following two basic types:

1) The constant driving-amplitude system -- the vibrating amplitude U_o of the driving unit can be set to the desired magnitude and kept at that value for various frequencies throughout the test.

2) The constant driving-force system -- the amplitude of the driving stress σ_o in the driving unit induced by the exciting field is maintained constant for all vibrating frequencies.

For the sake of simplicity, we represent the above-mentioned systems by the models given in Figures 1 and 2. In Figure 1, the driving unit is shown as a supporting floor which is oscillating at a fixed constant amplitude. Above the floor is the auxiliary unit "1" (or dummy) connecting the sample "2" to the driver. In Figure 2, the lower portion "1" represents the driving unit, with the exciting field not shown; the sample "2", in this case, is directly connected to the driver.

II. LONGITUDINAL VIBRATION, CONSTANT DRIVING AMPLITUDE

Let the motion of the floor, Figure 1, at time t be

$$U_o \cos\omega t \tag{2.1}$$

where U_o is a fixed constant and ω is the angular frequency of the oscillation. Using (1.4), we write the displacements in "1" and "2":

$$u_1 = \left[A_1 \cos\gamma_1 z + B_1 \sin\gamma_1 z \right] \cos\omega t \tag{2.2}$$

$$u_2 = \left[A_2 \cos\gamma_2 z + B_2 \sin\gamma_2 z \right] \cos\omega t \tag{2.3}$$

where γ_1 and γ_2 take the same identity as the expressions in (1.5) with the proper subscripts. If unit "1" is firmly attached to the floor and the top of unit "2" is free of stresses, then the boundary conditions and the continuity conditions at the interfaces are

$$\left(u_1\right)_{z=-\ell_1} = U_o \cos\omega t \tag{2.4a}$$

$$\left(u_1\right)_{z=0} = \left(u_2\right)_{z=0} \tag{2.4b}$$

$$\left[(E_1' + iE_1'')\frac{\partial u_1}{\partial z}\right]_{z=0} = \left[(E_2' + iE_2'')\frac{\partial u_2}{\partial z}\right]_{z=0} \tag{2.4c}$$

$$\left(\frac{\partial u_2}{\partial z}\right)_{z=l_2} = 0 \tag{2.4d}$$

Using these conditions, we obtain

$$u_1 = \frac{U_0}{D_0}\left[(E_1' + iE_1'')\gamma_1 \cos\gamma_1 z + (E_2' + iE_2'')\gamma_2 \tan\gamma_2 l_2 \sin\gamma_1 z\right]\cos\omega t \tag{2.5}$$

and

$$u_2 = \frac{U_0}{D_0}(E_1' + iE_1'')\gamma_1\left[\cos\gamma_2 z + \tan\gamma_2 l_2 \sin\gamma_2 z\right]\cos\omega t \tag{2.6}$$

where

$$D_0 = \left[(E_1' + iE_1'')\gamma_1 \cos\gamma_1 l_1 - (E_2' + iE_2'')\gamma_2 \tan\gamma_2 l_2 \sin\gamma_1 l_1\right]. \tag{2.7}$$

(2.5) and (2.6) indicate that, for a given value of z in either u_1 or u_2, the magnitude of the displacement relies on both the values of " E_1 " and " E_2 " of the system. If, however, we consider the ratio of the absolute values of

$$u_2(l_2) = \frac{U_0}{D_0}(E_1' + iE_1'')\gamma_1 \sec\gamma_2 l_2 \cos\omega t \tag{2.8a}$$

and

$$u_2(0) = \frac{U_0}{D_0}(E_1' + iE_1'')\delta_1 \cos\omega t \tag{2.8b}$$

we find

$$R = \left|\frac{u_2(l_2)}{u_2(0)}\right| = \frac{1}{\left[\sinh^2\left(\frac{\omega l_2}{C_2}\tan\frac{\delta_2}{2}\right) + \cos^2\left(\frac{\omega l_2}{C_2}\right)\right]^{1/2}} \tag{2.9}$$

containing only the properties in "2". Thus, it suggests that if we choose to use R_{max} instead of $[u_2(l_2)]_{max}$, the conventional way, as the criterion for determining C_2, then the difficulty due to coupling the sample with the supporting system will not enter the problem.

If $f_{r0} = \frac{\omega_{r0}}{2\pi}$ is the frequency of the fundamental mode when R reaches R_{max}, we find, from (2.9), that

$$C_2 = 4 f_{r0} l_2 \left(1 + \tan^2\frac{\delta_2}{2}\right) \tag{2.10}$$

and

$$\tan\frac{\delta_2}{2} = \frac{2}{\pi R_{max}} \tag{2.11}$$

Using the relationship given in (1.5b) for C and E^* and substituting it in (2.10) yields

$$E_2^* = 16 f_{r0}^2 l_2^2 \rho_2 \left(1 + \tan^2\frac{\delta_2}{2}\right). \tag{2.12}$$

Hence, the dynamic properties of a visco-elastic material can be determined from R_{max} and f_{ro} by use of (2.11) and (2.12).

It is obvious that, for elastic materials, (2.12) reduces to

$$E_2 = 16 f_{ro}^2 \ell_2^2 \rho_2 \tag{2.13}$$

It should be mentioned at this point that f_{ro} in most cases will not be the same as the commonly termed resonance frequency, f_o, since the former is the indication for $R = R_{max}$; while the latter is obtained from $[u_2(\ell_2)]_{max}$, which, as mentioned before, depends on the coupling nature of the sample and the driver. When $\ell_1 = 0$ in Figure 1, we obtain the case of a specimen attached directly to the floor. Then, from (2.6a) and (2.9), we have

$$\left| u_2(\ell_2) \right| = R U_o \tag{2.14}$$

giving $f_{ro} = f_o$ in this special case.

Using (2.9), a chart showing R vs $\frac{\omega \ell_2}{c_2}$ for various values of $\tan\frac{\delta_2}{2}$ is presented in Figure 3. It may be of interest to note that the presence of the factor $\tan\frac{\delta_2}{2}$ damped the amplitude and also shifted the peak-point of R.

III. LONGITUDINAL VIBRATION, CONSTANT DRIVING FORCE

Let the stress introduced in "1" of Figure 2 by the exciting field be

$$\sigma_o \cos \omega t \tag{3.1}$$

where σ_o is a constant. The boundary conditions, in this case, become

$$\left[(E_1' + i E_1'') \frac{\partial u_1}{\partial z} \right]_{z=-l_1} + \sigma_o \cos \omega t = 0 \tag{3.2a}$$

$$\left[(E_1' + i E_1'') \frac{\partial u_1}{\partial z} \right]_{z=0} + \sigma_o \cos \omega t = \left[(E_2' + i E_2'') \frac{\partial u_2}{\partial z} \right]_{z=0} \tag{3.2b}$$

$$(u_1)_{z=0} = (u_2)_{z=0} \tag{3.2c}$$

$$\left(\frac{\partial u_2}{\partial z} \right)_{z=l_2} = 0 \tag{3.2d}$$

Using the same expressions given by (2.2) and (2.3) for u_1 and u_2 with the above boundary conditions, we find

$$u_1 = -\frac{\sigma_o}{D_o'} \left\{ (1 - \cos \gamma_1 l_1) \cos \gamma_1 z + \left[\sin \gamma_1 l_1 + \frac{(E_2' + i E_2'') \gamma_2}{(E_1' + i E_1'') \gamma_1} \tan \gamma_2 l_2 \right] \sin \gamma_1 z \right\} \cos \omega t \tag{3.3}$$

and

$$u_2 = -\frac{\sigma_o}{D_o'} (1 - \cos \gamma_1 l_1) \left[\cos \gamma_2 z + \tan \gamma_2 l_2 \sin \gamma_2 z \right] \cos \omega t \tag{3.4}$$

where

$$D_o' = (E_1' + iE_1'')\gamma_1 \sin\gamma_1 \ell_1 + (E_2' + iE_2'')\gamma_2 \tan\frac{\gamma_2 \ell_2}{2} \cos\gamma_1 \ell_1 \qquad (3.5)$$

Note that these two expressions are very similar to those of (2.5) and (2.6). Therefore, it is expected that the same criterion can also be used here. In fact, the ratio of $|u_2(\ell_2)|$ over $|u_2(0)|$ from (3.4) is identical to that of (2.9). Thus, we may conclude that (2.11) and (2.12) are also applicable to this model in determining E_2^* and $\tan\frac{\delta_2}{2}$. And, as a matter of fact, these two equations can be applied to any other models if one end of the testing sample is free and the other end is firmly attached to a driving unit.

Rewriting the terms inside the square parenthesis of (3.4)

$$[\cos\gamma_2 z + \tan\gamma_2 \ell_2 \sin\gamma_2 z] = \frac{\cos\gamma_2(\ell_2 - z)}{\cos\gamma_2 \ell_2} \qquad (3.6)$$

and noting that $\cos\gamma_1 \ell_1$, $\cos\gamma_2 \ell_2$ and D_o' are all constants for a given system, we find

$$|u_2(z)| = K(\cos^2\alpha + \sinh^2\alpha')^{1/2} \qquad (3.7)$$

where

$$\alpha = \frac{\omega}{c_2}(\ell_2 - z), \quad \alpha' = \alpha \tan\frac{\delta_2}{2}. \qquad (3.8a,b)$$

and K is a constant depending on σ_0 and the properties in the system. (3.7) indicates the configuration of the standing wave in "2" is the combination of a sinusoidal function plus a hyperbolic function. To illustrate this phenomenon we plot, Figure 4, $|u_2(z)|/K$ for the cases of $\tan\frac{\delta}{2}$ = 0, 0.1, 0.2 and 0.3 when $f = f_{r0}$. It is seen that for elastic materials the configuration is a quarter wave with the nodal point at $z = 0$, while those of the visco-elastic materials exhibit the minimum but non-zero values at this point.

IV. TORSIONAL VIBRATIONS

When considering torsional vibrations, we shall confine ourselves to the samples of circular cylinders and use cylindrical coordinates for convenience. Let the coordinates be r, θ and z, with z as the axis of the cylinder, and the corresponding displacements be u_r, u_θ and u_z. In the propagation of torsional waves, no longitudinal or lateral displacements are to be expected and the motion is symmetrical about the axis of the cylinder. Therefore, u_r and u_z must both vanish and we need to consider only the wave equation for u_θ which, in the elastic case, may be written as:

$$\rho \frac{\partial^2 u_\theta}{\partial t^2} = \mu\left(\frac{\partial^2 u_\theta}{\partial z^2} - \frac{u_\theta}{r^2} + \frac{1}{r}\frac{\partial u_\theta}{\partial r} + \frac{\partial^2 u_\theta}{\partial r^2}\right) \qquad (4.1)$$

where μ is the Lame's constant

$= G$ the elastic shear modulus

If the torsional stress applied to the specimen varies sinusoidally with time and the strain thus induced also varies sinusoidally but with a phase difference, then we may rewrite (4.1) for visco-elastic materials as:

$$\rho \frac{\partial^2 u_\theta}{\partial t^2} = (G' + iG'')\left(\frac{\partial^2 u_\theta}{\partial z^2} - \frac{u_\theta}{r^2} + \frac{1}{r}\frac{\partial u_\theta}{\partial r} + \frac{\partial^2 u_\theta}{\partial r^2}\right) \qquad (4.2)$$

where G' and G'' are the real and imaginary parts of the complex shear modulus " G ".

Note that u_θ is a function of r, z and t. If we assume

$$u_\theta = r F(z,t) \tag{4.3}$$

then it leads to

$\tau_{r\theta}$, the shearing stress in θ -direction on r - plane,

$$= (G' + iG'') r \frac{\partial}{\partial r}\left(\frac{u_\theta}{r}\right) = 0$$

which together with $\tau_{rr} = 0$ and $\tau_{rz} = 0$, from $u_r = 0$ and $u_z = 0$, will satisfy the boundary conditions of free stresses along the surface of the cylinder. Substituting (4.3) in (4.2), we obtain

$$\rho \frac{\partial^2 F}{\partial t^2} = (G' + iG'') \frac{\partial^2 F}{\partial z^2} \tag{4.4}$$

with F being a function of z and t. Since (4.4) is identical with the longitudinal wave equation previously obtained, it suggests that a similar procedure can be followed.

Let us now use (4.4) to consider the torsional vibration problem, Figure 5, in which a cylindrical sample is attached to a floor that is oscillating according to

$$\varepsilon_0 \cos\omega t \tag{4.5}$$

where θ_0 is the amplitude of the angular rotation and is constant for various vibrating frequencies.

The function F satisfying (4.4), in view of its similarity to (1.3), may be assumed of the form

$$F(z,t) = [A\cos\beta z + B\sin\beta z]\cos\omega t \tag{4.6}$$

where

$$\beta = (1 - i\tan\tfrac{\delta'}{2})\frac{\omega}{C_s} \tag{4.7a}$$

C_s = shear wave velocity

$$= \left(\frac{G^*}{\rho}\right)^{1/2}\sec\frac{\delta'}{2} \tag{4.7b}$$

$$G^* = (G'^2 + G''^2)^{1/2}, \quad \tan\delta' = \frac{G''}{G'} \tag{4.7c,d}$$

and A and B are constants to be determined from boundary conditions.

The boundary conditions at both ends of the cylinder are

$$u_\theta(r,0,t) = r\theta_0\cos\omega t \tag{4.8a}$$

and

$$\left(\frac{\partial u_\theta}{\partial z}\right)_{z=l} = 0 \tag{4.8b}$$

Using (4.3), we transform (4.8a) and (4.8b) to

$$F(0,t) = \theta_0 \cos\omega t \tag{4.9a}$$

and

$$\left(\frac{\partial F}{\partial z}\right)_{z=\ell} = 0 \quad , \tag{4.9b}$$

which are exactly the same conditions as those in the first longitudinal vibration problem when $\ell_1 = 0$. Thus, from analogy, if

$$R' = \left|\frac{u_\theta(r,\ell,t)}{u_\theta(r,0,t)}\right| \tag{4.10}$$

and f_{so} is the frequency when R' reaches R'_{max} for the fundamental mode, then

$$G^* = 16 f_{so}^2 \ell^2 \rho \left(1 + \tan^2\frac{\delta'}{2}\right) \tag{4.11}$$

and

$$\tan\frac{\delta'}{2} = \frac{2}{\pi R'_{max}} \tag{4.12}$$

giving the components of a complex shear modulus "G".

It should be mentioned, from the results obtained in the longitudinal vibration problems, that (4.11) and (4.12) can also be applied to more complicated cases, where the amplitude of rotation at the base of the sample varies with the vibrating frequency.

V. DISCUSSION

Expressing $C_1 = 2 f_1 \ell_1^{\,8}$, $C_2 = 2 f_2 \ell_2 \left(1 + \tan^2 \frac{\delta_2}{2}\right)$ and $\chi = \pi \frac{f}{f_2}$, we write the vibration amplitude at the top of the sample from (3.4) to a suitable form for computation

$$\frac{|u_2(\ell_2)|}{\sigma_0 \ell_1 / \rho_1 C_1^2} = \frac{(1 - \cos N\chi)}{N\chi (S^2 + W^2)^{1/2}} \qquad (5.1)$$

where

$$S = \sin N\chi \cos L\chi \cosh L'\chi + \frac{N}{M} \cos N\chi \left(\tan \frac{\delta_2}{2} \cos L\chi \sinh L'\chi + \sin L\chi \cosh L'\chi\right) \qquad (5.2a)$$

$$W = \sin N\chi \sin L\chi \sinh L'\chi + \frac{N}{M} \cos N\chi \left(\tan \frac{\delta_2}{2} \sin L\chi \cosh L'\chi - \cos L\chi \sinh L'\chi\right) \qquad (5.2b)$$

$$L = \frac{1}{1 + \tan^2 \frac{\delta_2}{2}} \quad , \quad L' = L \tan \frac{\delta_2}{2} \qquad (5.2c,d)$$

$$N = f_2 / f_1 \quad , \quad M = \rho_1 \ell_1 / \rho_2 \ell_2 \qquad (5.2e,f)$$

f_i is the natural frequency of a cylinder vibrating alone in its fundamental longitudinal mode with i = 1 and 2 for the driver and the specimen, respectively. For a given system, the value of $|u_2(\ell_2)|$ in (5.1) varies only with χ. Thus, when $|u_2(\ell_2)|$ reaches a maximum, we obtain the resonance frequency ratio $\chi_0 = \pi \frac{f_0}{f_2}$. Arbitrarily assigning the values of N and M, we then obtain the

---

8. The driving unit is assumed as elastic material to simplify the calculation.

plot of f_1/f_2 against f_0/f_2, Figure 6, which may be used to compare with the results from the conventional method based upon the equation

$$M \tan N\chi_0 + N \tan \chi_0 = 0 \qquad (5.3)$$

given by Quimby[9] and used by many others[10].

It is seen, from Figure 6, that results from the conventional method, (5.3), shown in solid dots, are not accurate in calculating f_2 from f_0 for materials of large internal friction. The accuracy is also affected by the natural frequency ratio of the driving unit to the sample. Therefore, if one should choose to use the conventional method, the testing system should be designed with f_1/f_2 close to unity[11] to limit the effect from the variations of M and $\tan\frac{\delta}{2}$. However, if the method presented here is used, the matching of the natural frequencies will not be necessary, allowing us to use the same driving unit throughout the entire work. Furthermore, the expressions (2.11) and (2.12) for longitudinal vibrations and (4.11) and (4.12) for torsional vibrations bear direct relationship between the measured items and the dynamic properties and are simple to use.

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9. Reference 1.

10. References 2, 3 and 4.

11. It agrees with the finding from Terry, reference 4, that for accurate measurements the transducer had to be selected so as to have a natural frequency approximately equal to or higher than that of the specimen.

ACKNOWLEDGMENT

The author wishes to express his gratitude to Dr. A. Assur for his encouragement in this work. He also wishes to thank Messrs. J. Smith and N. Smith for their valuable work in carrying out the numerical computations through the digital computer.

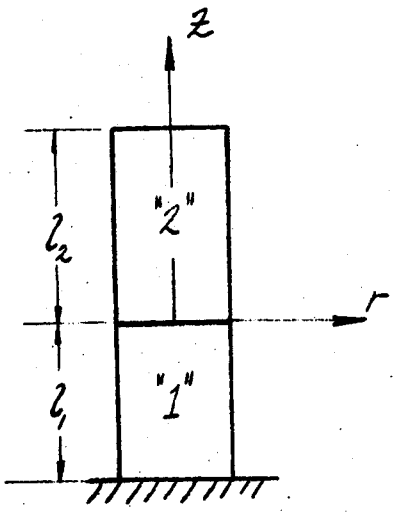


Fig. 1. Constant driving amplitude system

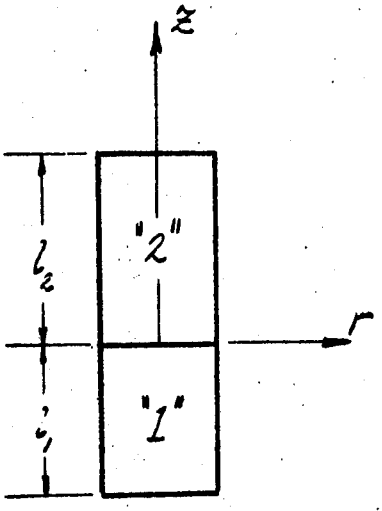
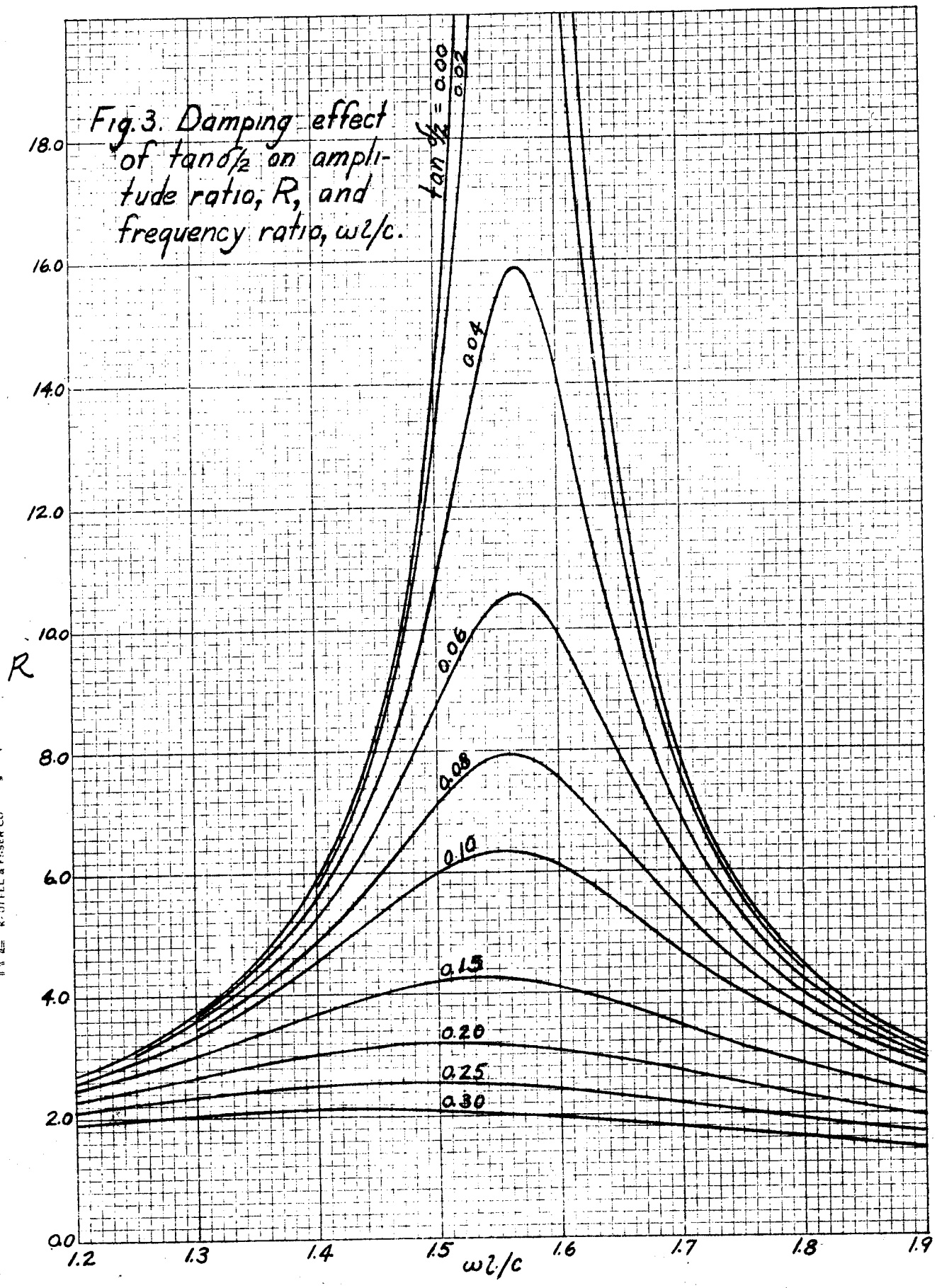


Fig. 2. Constant driving force system



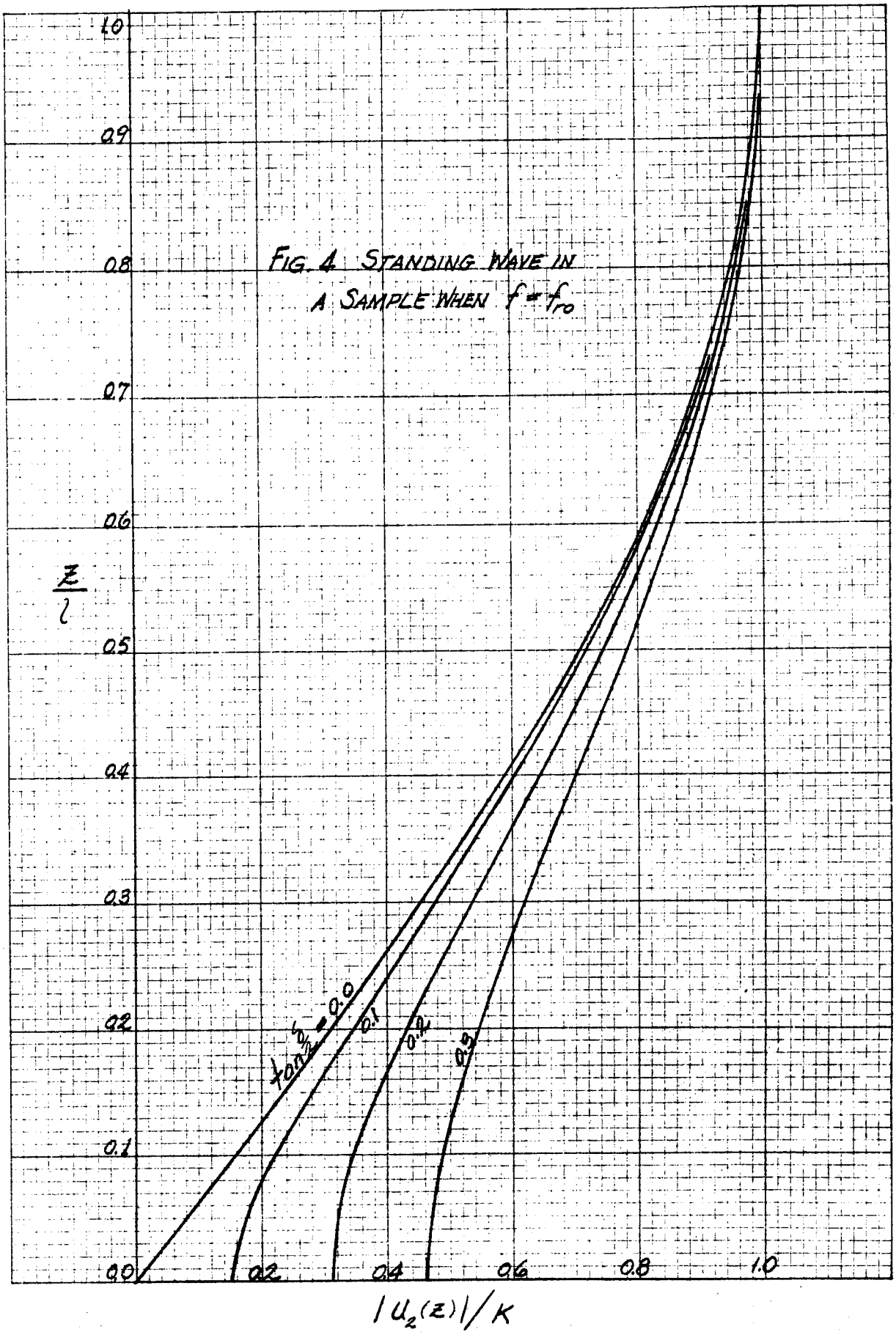


FIG. 4 STANDING WAVE IN A SAMPLE WHEN $f = f_{ro}$

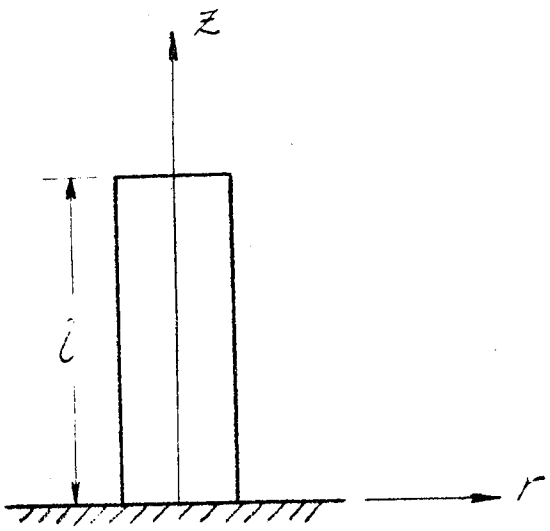


Fig. 5. Circular cylinder for torsional vibration

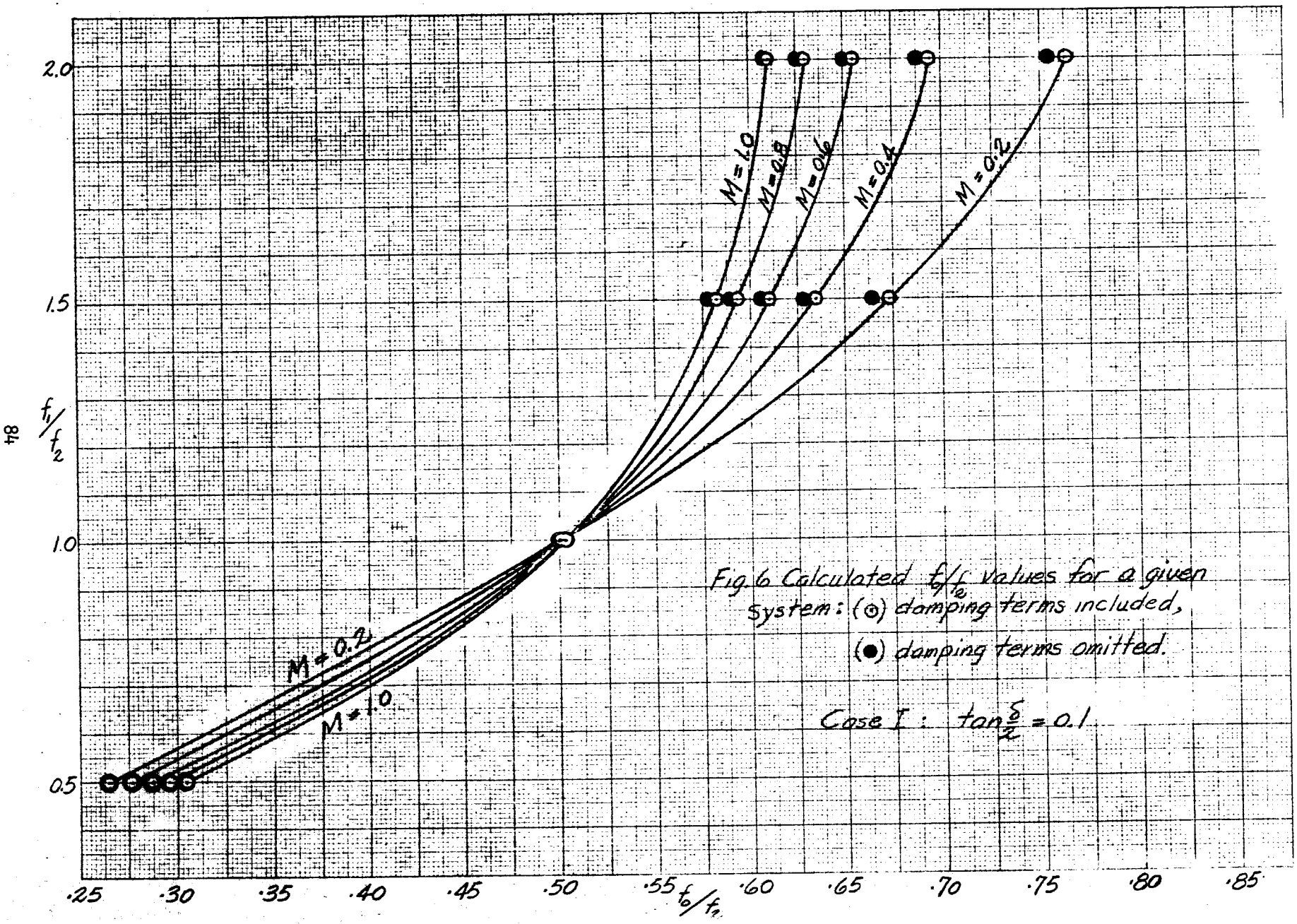


Fig. 6 Calculated f_b/f_2 values for a given system: (⊙) damping terms included, (●) damping terms omitted.

Case I: $\tan\frac{\delta}{2} = 0.1$

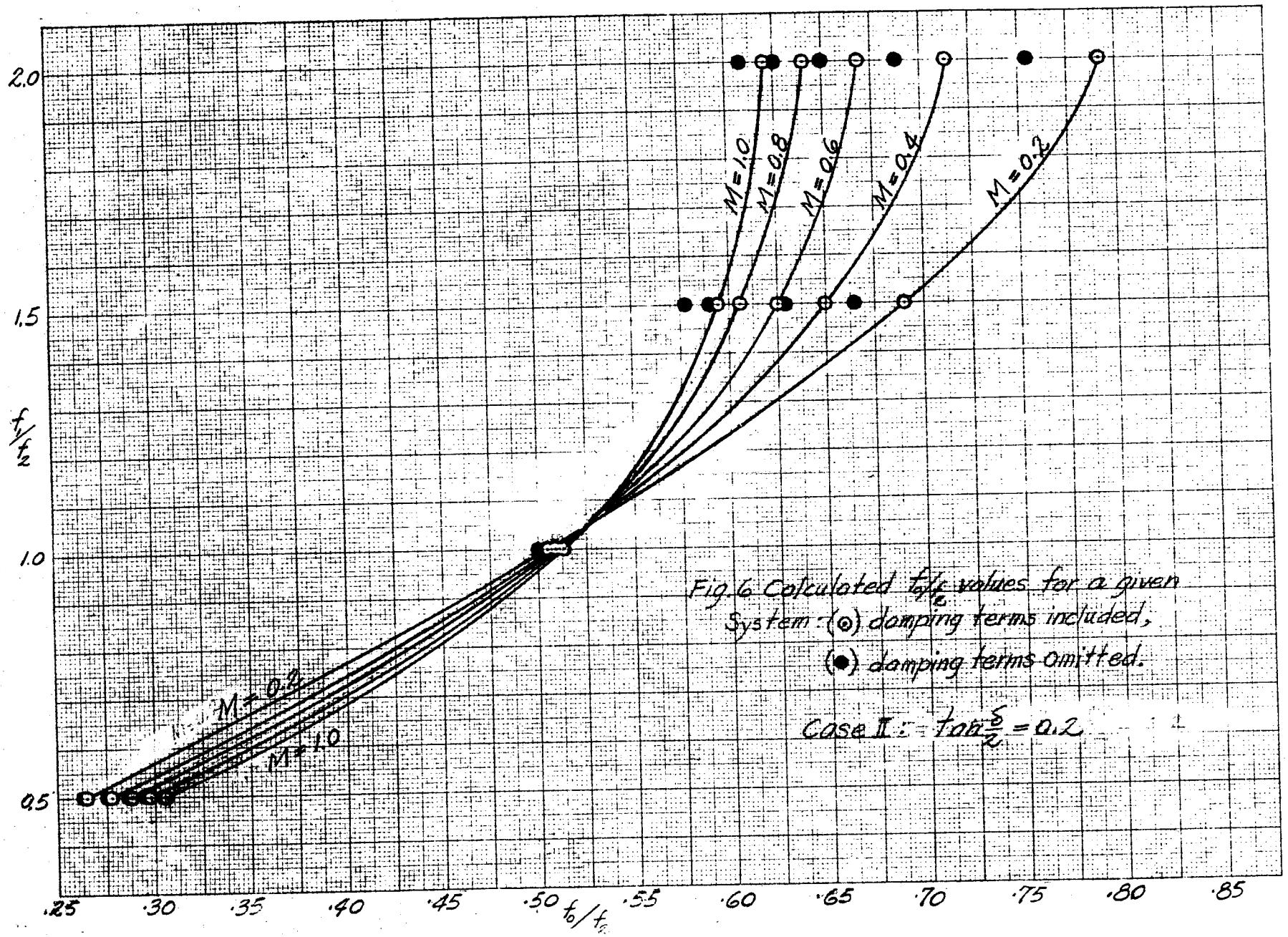


Fig. 6 Calculated f_1/f_2 values for a given system: (⊙) damping terms included, (●) damping terms omitted.

Case II: $\tan\frac{\delta}{2} = 0.2$

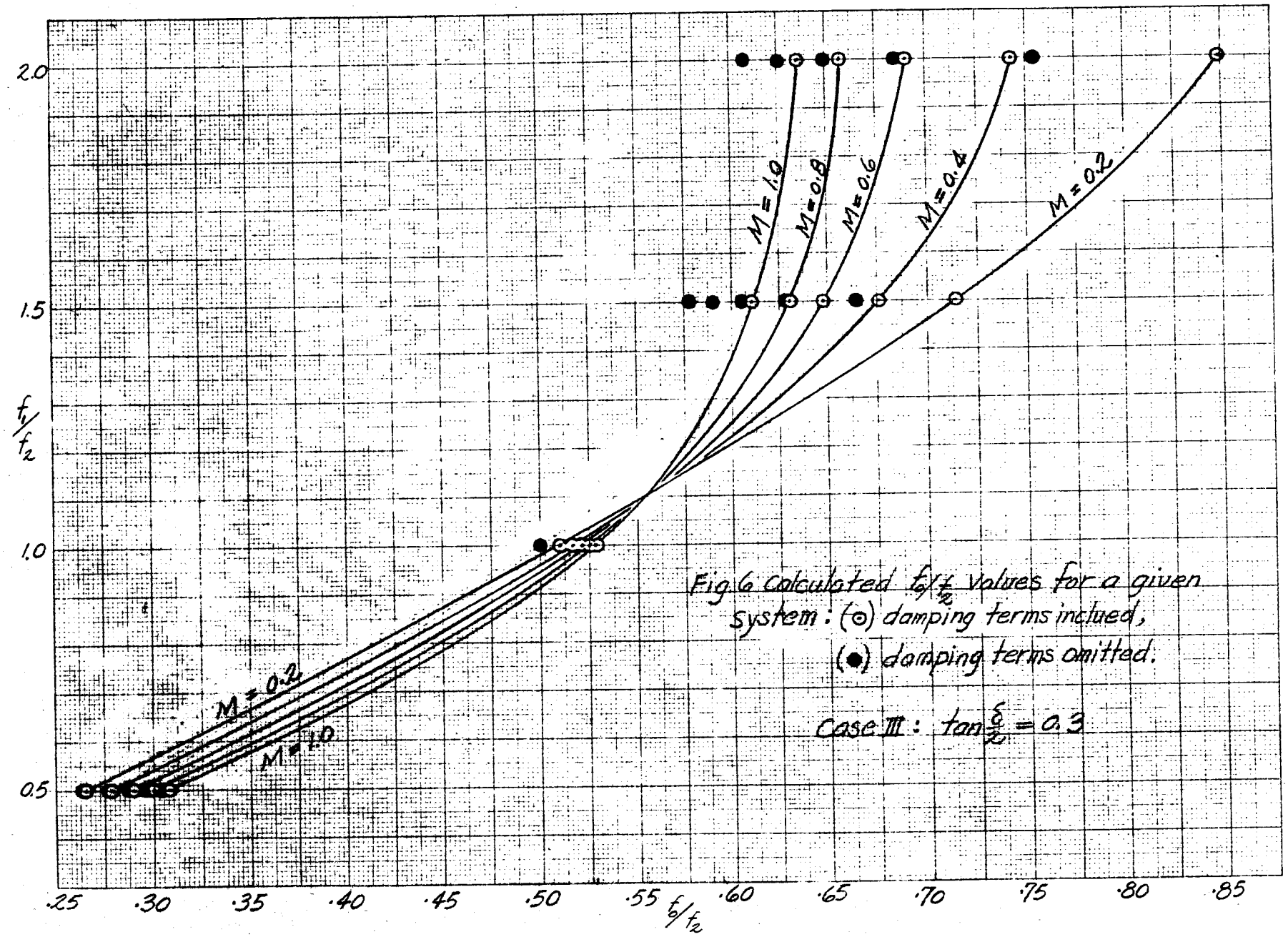


Fig 6 Calculated f_b/f_2 values for a given system: (⊙) damping terms inclued, (●) damping terms omitted.

Case III: $\tan\frac{\delta}{2} = 0.3$

STRUCTURAL CHANGES IN NYLON BODY ARMOR FABRICS DUE TO IMPACT

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By

Dr. George Susich

Introduction

The resistance of the nylon body armor vest to fragment simulator missiles is generally tested ballistically. A panel is impacted under standard conditions by varying the striking velocity of the missile. The value of the panel is obtained by observing at what striking velocity do missiles completely penetrate. Such conventional tests are carried out relatively easily and give fairly reliable results concerning the protection of the panel. They do not provide, of course, any information about the mechanisms of penetration. This can be obtained by investigating the structural changes occurring in the panel. Therefore, in connection to ballistic tests, a systematic study was carried out using microscopic and X-ray diffraction techniques.

Description of Materials Tested

A nylon fabric panel was investigated after it was impacted by 20 missiles at striking velocities between 1,098 and 1,398 ft/sec. The exit velocity of the missiles was not measured in these tests.

Slide 1 shows the 17 grain fragment simulator steel missile. The panel was fully penetrated only by those missiles which had striking velocities higher than about 1,190 ft/sec because the corresponding kinetic energy of the missile (706,000 g-cm) could be absorbed by the panel. The panel is a complex nylon fabric and consists of 12 identical layers. Each layer has a rather simple fabric geometry: 2x2 basket weave made from identical warp and filling yarns (slide 2). The panel fails only after all layers have been penetrated.. We shall see, however, that at a given striking velocity the damage in each layer is by no means identical but markedly different. From the 20 missiles eight did not go through the panel because their kinetic energy was lower than that the panel could absorb. X-ray pictures from the front and top of the panel (slide 3) show the location and position of the missiles retained by the panel. It can be observed that most missiles did not go directly through the panel but turned around before they were stopped. It is obvious that after such "tumbling" more nylon yarns of the panel could resist penetration. The "tumbling" of missiles

is, however, beyond the control of the ballistic tests performed. Failure and resistance of the panel will be easier understood if we do not consider only the alterations of the panel but also the changes in the individual fabric layers, and in its elements warp and filling yarns, even in single filaments.

Methods and Results of the Investigations Performed

1. Standard Nylon Panel and Its Elements

For the microscopic observations parts of the panel around holes (about 1x1 inches square) were embedded in a plastic. Then cross-sections were made through the panel by a sliding microtome in three mutually perpendicular directions. This permitted to obtain a three dimensional impression of the permanent changes occurring in the panel. Slides 4 and 5 show a sequence of cross-sections made perpendicular to the fabric surface at levels only a few millimeters apart from each other. Slide 4 demonstrates warp cross-sections from a complete penetration, while slide 5 shows filling cross-sections of a partial penetration after the missile has been removed. Slide 6 demonstrates sections through the first layers of a completely penetrated panel made parallel to the fabric surface.

What can we observe from these cross-sections?

1. After penetration of the missile the holes remaining in the panel are narrower than the cross-section of the missile. During penetration the yarns are extended, but they recover due to the elasticity of nylon.

2. Within the holes broken and unravelled yarns are observable. They are aligned in the direction of missile movement similarly to the orientation of solid particles of longitudinal shape in the current of liquids or air.

3. The "tumbling" of the missile during penetration can be recognized.

4. The fabric structure close to the holes remains almost undistorted. Apparently at high impact velocities dissipation of energy does not occur in the fabric. Only in exit layers, where the missile velocity already has been markedly reduced, remains some distortion of the fabric structure visible around holes.

Slide 7 shows the exit surfaces of four individual layers separated from a partially penetrated panel. Here only seven layers have been penetrated, and the panel gave--under the condition of the tests performed--full protection. If a layer was penetrated, broken yarns and filaments protruding from the holes are visible. They are not any more separable

from each other as originally, but they stick together. Different types of damages appear in individual layers. They are diminishing in the direction of missile movement. In the sixth layer, e.g. warp yarns were not broken, and in the eighth layer only a permanent bulge of the fabric remains observable.

For the evaluation of damages warp and filling yarns have been removed around holes in the same order as they have been originally in fabric layers. Slide 8 demonstrates this procedure which allows the counting of broken and damaged yarns. The two tables (slide 9 for a complete, and slide 10 for a partial penetration) show the results obtained. (Broken yarns are marked here by crosses, and damaged yarns by dots.) Both tables give essentially the same results. In the entrance layers a relatively great number of yarns (12-13) have been broken, their number diminishes in each layer with decreasing velocity of the missile. As the panel has been completely penetrated in the last layer only two yarns have been broken. It became evident again that in each layer the damage is different, and that the missile pushes apart yarns during its penetration. It is obvious that the yarns pushed away from the path of the missile are more or less ineffective in resisting the penetration. These yarns originally have been extended but not up to their breaking point. Therefore, they could not extract from the missile, the entire energy necessary for their rupture.

It was of interest to estimate how much energy was absorbed by extending and breaking yarns in the individual layers. For this purpose, a dyeing technique had to be used permitting to measure that length of each yarn which was actually extended and broken by the missile. For dyeing served Fastusol Direct Blue LBRRA. While unimpacted yarns appear after dyeing slightly blue, impacted parts of yarns are dark blue. During impact moving of single filaments along and across each other occurs. This causes fibrillation--splitting up of filaments into much thinner fiber units--known as fibriles. Fibrillated filaments show much heavier dye uptake than unimpacted fibers. Broken fiber ends are also dyed darker blue.

Slide 11 demonstrates yarns removed from impacted layers after dyeing. Slide 12 shows individual yarns at a slightly larger magnification.

The calculation of the energy necessary for extending and rupture of yarns was based on the following consideration. Under static conditions 85 g-cm/gx/m energy is necessary for the extension and rupture of HT Nylon. At impact conditions this energy is reduced to about 44 g-cm/gx/m. For any estimation of the energies involved we have to know what length of yarns have been extended by the missile before rupture occurred. This was possible by counting the broken yarns and measuring the dyed portion on individual yarns. It was found that each layer extracts less energy from the missile as the missile passes through the panel. The first layer,

e.g. absorbed 5,230 g-cm and the last only 3,650 g-cm energy at the complete penetration of the panel at a striking velocity of 1,340 ft/sec, corresponding to a striking energy of 859,000 g-cm. These energies are only 0.6, respectively 2.2% of the actual impact energy for the layer. They show that the protection of the layers is more efficient at lower impact energies. It was found that not more than 7% of the original kinetic energy of the missile (this varied between 600,000 and 1,370,000 g-cm) was necessary for extending and breaking yarns, either in complete or partial penetrations of the panel.

Sections through the impacted panel have been investigated also in polarized light. This method permits measuring the birefringence, orientation, and stretching of individual filaments. It was observed (in contrast to original expectations) that the stretching of filaments around holes after impact is less than originally. This is due to the fact that although filaments around holes have been extended, they have been softened and contracted after the missile passed through the layer.

Already the fused ends of yarns in holes (shown in slide 7) and their sticking together indicates that some melting of nylon filaments took place. In impact tests thickened mushroomlike ends of broken filaments have been frequently observed. They were interpreted as softening and melting of nylon. The thickened almost spherical fiber ends indicate contraction after fusion of nylon. Taking into account the specific heat (0.51 cal/g) and the heat of melting (39.5 cal/g) of nylon it could be estimated how much kinetic energy of the missile was needed for melting of yarns. Calculations were made for a complete and a partial penetration. About 26% of the missile energy was transformed into heat.

The cross-sections of unimpacted HT Nylon filaments appear anisotropic, or almost anisotropic in parallel polarized light. If the mushroomlike ends of fibers are observed in polarized light sometimes a spherulitic structure is visible. This shows that in this part of filaments indeed melting took place. After cooling a slow recrystallization and formation of crystal needles in spherulitic arrangements occurred. Statements about melting of nylon raised earlier some objections.

The X-ray diffraction patterns of impacted fibers corroborates, however, that nylon filaments melt in the impacted area. Slide 13 demonstrates the X-ray diffraction techniques using the Norelco X-Ray Diffraction Micro Camera with a flat film. We see the pinhole and individual yarns before the opening. Slide 14 shows X-ray diagrams of nylon yarns. Before impact HT Nylon yarns give a fiber diagram which reveals rather high orientation and marked defects in the nylon crystal lattice due to the stretching process. After impact, however, a randomization of the originally aligned polyamide chains occurred. Now rather sharp interference rings are visible in the diagram indicating that disorientation and recrystallization took place due to heat.

II. Individual 2x2 Basket Weave Nylon Fabrics

The response of single layers to impact was also investigated. In these ballistic tests, fabrics have been impacted between 488 and 1,991 ft/sec striking velocities of the missile. Not only striking, but also exit velocities of the missile have been measured. This permitted to obtain values of the energy lost by the missile after it passed through the fabric.

If the striking velocity of the missile increased, the energy extracted from the missile diminished from 79% to 56% of its original energy. This shows again that the fabric is more effective at relatively low impact energies. With increased striking velocities the number of broken yarns in layers increased, however, from 9 to 16 yarns. At lower striking energies apparently more yarns can be pushed away without extending and breaking them. If we calculate how much energy was necessary for breaking individual yarns at varied velocities we see that the yarns absorbed much more energy (8,000 g-cm) at low striking velocities, than at high velocities (3,230 g-cm). This can be understood since under severe impact conditions more softening of nylon takes place, which diminishes the energy required for its rupture.

Summary

The testing methods described show different types of permanent damages occurring in individual fabric layers, in yarns and in filaments of a panel under impact conditions. They permit a calculation, or at least an estimation of the energies absorbed. Therefore, they are informative beyond results obtainable from conventional ballistic tests. The methods also show how much the panel and its elements fail, and they indicate improvements mandatory for increasing the resistance of protective materials at severe conditions of impact. The described testing methods should be, of course, extended to fabric like structures made of materials other than nylon. Such are fabrics from strong metal wires preferably with low density, and composite structures containing beside metallic yarns such plastic materials which are stronger and more resistant to high temperatures than nylon.

Fourteen photographs were submitted with Dr. Susich's paper. These photographs could not be reproduced. The titles are listed in the order that the slides were shown.

1. Fragment Simulator Steel Missile
2. Yarns Removed from 2x2 Nylon Fabric
3. X-ray photographs of Nylon Panel
4. Warp Cross-Sections of a Nylon Panel Around a Completely Penetrated Hole
5. Filling Cross-Sections of a Nylon Panel Across a Partially Penetrated Hole
6. Cross-Sections Parallel to Panel Surface Completely Penetrated Hole
7. Exit Side of Layers Separated from Nylon Panel
8. Fabric Layers and Threads Separated from a Body Armor Panel Around a Hole
9. Broken and Damaged Yarns in Panel Complete Penetration (Table)
10. Broken and Damaged Yarns in Nylon Panel Partial Penetration (Table)
11. Yarns from Impacted Fabric Layers
12. Before Impact - After Impact
13. Micro X-ray Diagrams
14. X-ray Diagrams of Yarns

NONDESTRUCTIVE TESTING OF THE WORKMANSHIP OF A HIDDEN WELD

ARMY CHEMICAL CENTER, MARYLAND

By

Alfred N. Block

Since my last appearance before you, the Chemical Corps has changed its name. We are now the U. S. Army CBR Agency and an activity of the U. S. Army Munitions Command. However, we are still engaged in the same business and retain our responsibility for preparedness for chemical and biological warfare and radiological defense.

At several occasions, I have discussed with you one of our major problems: Securing the leak proofness of chemical munitions, which, as the name implies, are filled with toxic agents. Their weak spot is the closure (Figure 1).

An immediate leak in such munition is no problem. The void of the munition is filled with Hellum under approximately 5 psi pressure; every munition which comes from the filling line is helium-tested and agent tested, minute leaks are detected without difficulty, and the munition can be repaired before it is stored.

We are, however, concerned with minor defects in the closure assembly which might develop later on, perhaps after years of storage, into leaks and then create hazards. A crack in the closure of just 5-8 micron is a leak which for safety reasons is not acceptable. A foolproof Nondestructive test for establishing the workmanship of a closure is, therefore, of the upmost importance to us.

The closure under discussion here is a weld applied, of course, after the filling of the munition. We need a test for identifying munitions which have little cracks, small cavities or other minute deficiencies, that, while harmless now might deteriorate later on into leaks. The conventional test methods, X-rays, Ultrasonics, etc., do not serve the purpose. Therefore, for several years now, we have attempted to find more suitable approaches to the problem.

If I remember correctly, I have discussed with you vibration at resonant frequency (with major stress at the weld). It did not work.

Last year, however, we obtained at least an indication that we are finally on the right track: The exposure of a weld to thermal shock. The welded area was heated up to approximately 1300°F and then exposed to liquid nitrogen at -325°F. In later tests, room temperature tap water was used for the same purpose.

APPARATUS

The apparatus included an induction heating facility, a quenching system, miscellaneous instrumentation, and equipment for pressurizing the shells. During preliminary tests, modifications were made in equipment and procedures until sufficient results were obtained (Figure 2).

INDUCTION HEATING FACILITY

The objective was to heat the weld zone to nearly 1300°F. The National Bureau of Standards made available to DOFL a 250 kc, 15 kw input spark-gap converter manufactured by the Lepel High Frequency Laboratories, Inc. The especially designed coil for use with this converter was obtained directly from the Lepel Laboratories (Figure 3).

Preliminary checks (using the coil) showed that it required 6 minutes and 20 seconds for the inner surface of the weld to register 1300°F. The outer surface had reached 1400°F in this period. The long period of (heating) time was caused by the machine's high frequency that heats the outer layer first (e.g., the outer surface reached 1300°F in 2 minutes and 50 seconds) as well as its relatively low power rating. To rapidly generate heat in depth would have required low-frequency, high-power converter, not immediately available. Nevertheless, this heating time was acceptable for these tests.

QUENCHING SYSTEM

The apparatus (Figure 4) was designed to force liquid nitrogen through a rotating nozzle and spray it on the hot weld. Pressurized air provided the force and the flow was turned on and off by a hand-operated valve.

To determine the amount of liquid used per run, the liquid nitrogen tank was placed on a weighing scale. Air pressure controls are shown in Figure 5. A power oscillator was used to drive the motor at various speeds. The double-ended nozzle used for spot quenching permitted localized quenching in an alternating manner, as opposed to an overall spray quench. This system delivered over 12 pounds of liquid nitrogen per minute with nozzle speeds from 1 to 4 rpm.

OPERATION (PRELIMINARY TESTS)

The steps for operating were as follows:

a. Start induction heating

b. Start nozzle motor

c. Close hand-operated valve

d. Turn on and regulate air pressure after six minutes

e. Stop induction heating

f. Open hand valve

g. Quench for one minute

INSTRUMENTATION

Measurements were made on a shell (considered to be typical) to determine those parameters that would produce large stresses due to high temperature gradients. To measure the temperature distribution across the shell, thermocouples were mounted at various depths. Also, strain gages were mounted on the burster cylinder to measure strains proportional to the stress at the root of the weld.

THERMOCOUPLES

Spring-loaded thermocouples mounted close to the weld area proved to function adequately in measuring temperature distribution. The thermocouples used were Chrome-Alumel (type G) manufactured by Nanmac Corporation. They were monitored by a multichannel strip chart recorder.

STRAIN GAGES

Attempts to use foil strain gages to measure the true strains were unsuccessful. First the strains recorded were too great, indicating that the apparent strains (caused by temperature sensitivity of the gages) were large compared to actual strains. Second, quenching did not produce an appreciable change in the gage indications. Also, with time, the gage responses showed slow and unpredictable changes that usually resulted from holding the gages at temperatures exceeding their transition temperature of about 800°F.

PRESSURE TESTS

Leaks in the closure weld were checked by pressurizing the shell's cavity with a gas consisting of nitrogen mixed with a small quantity of refrigerant F-13. The seal was probed with a G. E. Model H-6 refrigerant detector, which can detect leaks as small as 0.5 ounce of refrigerant per year. This equipment is shown in Figure 6.

BASIC TEST PROCEDURE

The basic test was a cycle in which the time for heating and quenching were constants. The heating time of six minutes was taken from the Lepel tests during which approximately 1300°F was obtained at the inner surface. Duration of the quench was arbitrarily set at one minute. Test results showed this to be sufficient quenching time. The test for evaluating parameters was, therefore, one that involved heating for six minutes and quenching for one minute. The parameters tested included the type of coolant, amount of coolant, and nozzle speed.

LIQUID NITROGEN TESTS

Liquid nitrogen was initially used as a quenching agent because of its low temperature (-325°F), its noncorrosive properties, and its ability to vaporize completely after spraying. Nine runs were made to determine the effect of nozzle speed and the amount of coolant used. The nozzle speeds were 1, 2, and 4 rpm; coolant quantities were 8, 10 and 12 pounds per run.

The temperature gradients obtained varied with the amount of coolant used. There seemed to be no significant effect from nozzle speed. The maximum temperature difference measured was approximately 230°F using 12 pounds of coolant. Because this gave stresses of only about 50,000 psi, it was decided to replace nitrogen with water as a coolant.

WATER TESTS

Water tests were made with the apparatus described above. Several runs with approximately 12 pounds of water per run and a nozzle speed of 2 rpm resulted in temperature gradients above 800°F across the weld (or stresses above 160,000 psi). This was a considerable improvement over the results obtained using liquid nitrogen as a quencher and the stress levels obtained were considered to be sufficient to use in the attempt to rupture sound welds.

FINAL TESTS

Eight decontaminated shells were available for temperature shock testing. Reportedly, the shells had sound seal welds and were picked at random; before temperature shock testing, however, the shells were rechecked for leaks.

INITIAL LEAK TEST

The shells were tested by pressurizing the cavity (up to 1000 psi) and probing the weld and inner cylinder for leaks as described before. No leaks were found in any of the eight shells. The procedure included:

a. Pressurizing the cavity

b. A period of three to five minutes delay to permit an accumulation of refrigerant in case a small leak existed.

c. Removing the shell cap and probing the weld and inner cylinder for traces of refrigerant that would indicate a leak.

d. Releasing the pressure

TEMPERATURE SHOCK TESTS

Test procedure consisted of three cycles of thermal shock. The heat was on for 6 minutes during the first run and for 5-1/2 minutes during the second and third runs. In each case, quenching was stopped when the shell was full of water. The water was siphoned off after each cycle. All shells were tested with empty cavities, except for S/N 333, which was filled with Prestone as a simulant so that its temperature could be monitored (the maximum allowable temperature being 165°F). At the end of three cycles the Prestone temperature had reached 100°F.

As opposed to the preliminary runs, the induction heating coil was lowered an additional 1/4 inch, making a total of 1-1/2 inches below the top. This change was made to concentrate the heat nearer to the weld area, which was not possible in the preliminary tests because the thermocouples were in the way. All eight shells were subjected to thermal shock and then set aside for leak tests.

FINAL LEAK TESTS

The procedure for testing for leaks was identical to that given before except that the pressure was 500 psi instead of 1000 psi. The reason for the change was to avoid exhausting the supply of nitrogen and F-13. Also additional leaks might have been detected if the shells had been retested at 1000 psi.

Three out of the eight shells tested developed leaks. After the eight shells were pressure tested, some were filled with water to localize the leaks, which were found to be between the weld and outer casing.

CONCLUSIONS

The shells which were subjected to thermal shock testing were originally leakproof. They had withstood 1000 psi pressure tests. Three of the shells which were thermal shock tested developed various degrees of leakage. This leads to the conclusion that thermal shock testing distinguishes between "good" and "bad" welds. It gives us an indication that thermal shock testing might be applicable for identifying chemical munitions that are apt to develop into leakers during storage.

FUTURE INTENTIONS

1. It will be important first to determine the nature of those welds which leak after their exposure to thermal shock testing. The test is of value only if the immediate leakage reveals defects and imperfections of the weld which will turn the munition concerned into a leaker at some later time. Sectionalizing of welds of this kind might provide the answer.

2. If there is a relationship between the "inclination of a munition" towards future leakage and the actual break of its closure during thermal

shock testing, it will be important to determine that range of stresses to be applied to the weld that truely leads to a distinction between "good" and "bad" welds.

The investigation described here was ably conducted by the Diamond Ordnance Fuse Laboratories in Washington, D. C., under the leadership of Mr. Rezneck.

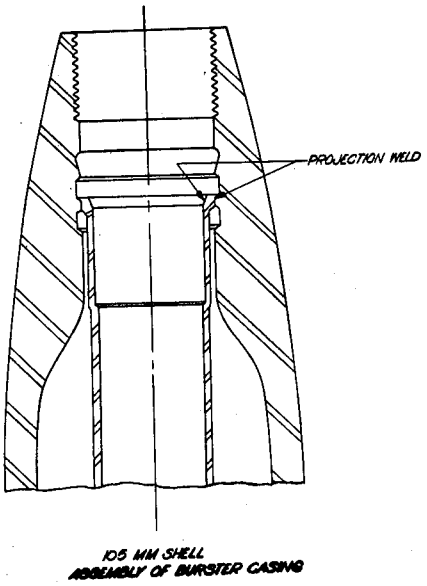


FIGURE 1

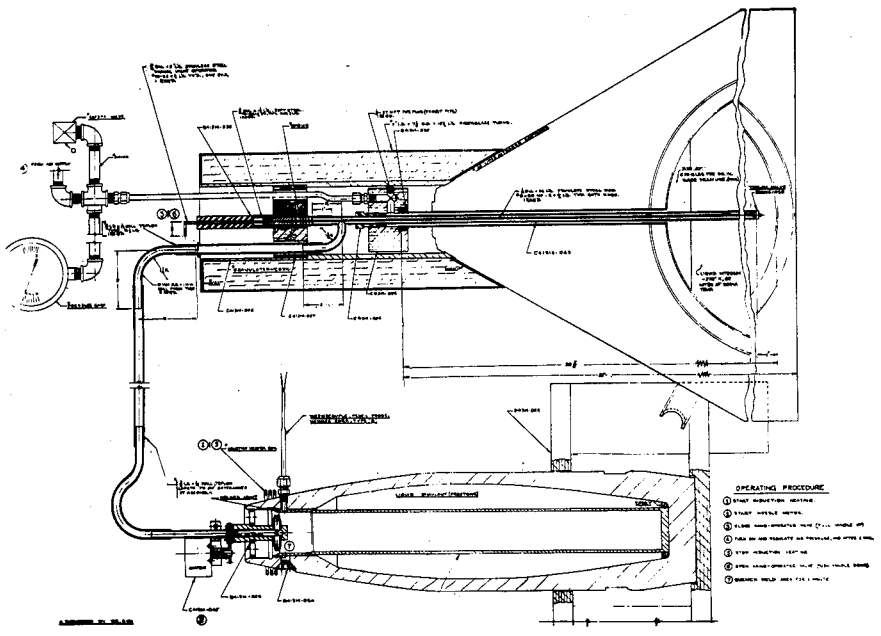


FIGURE 2

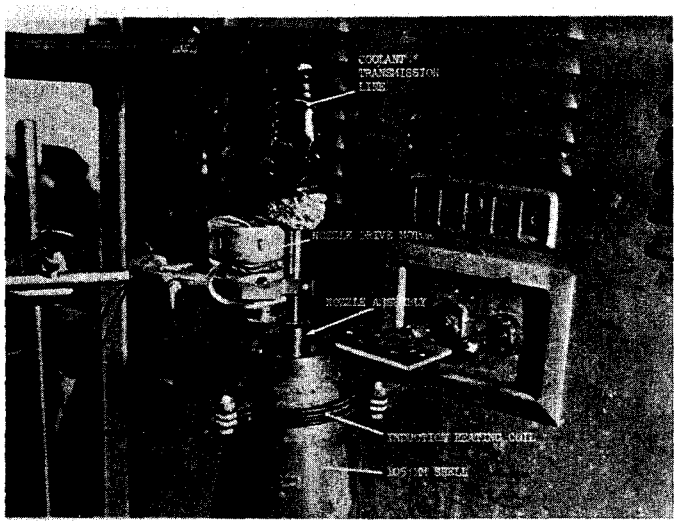


Figure 3. The induction heating facility

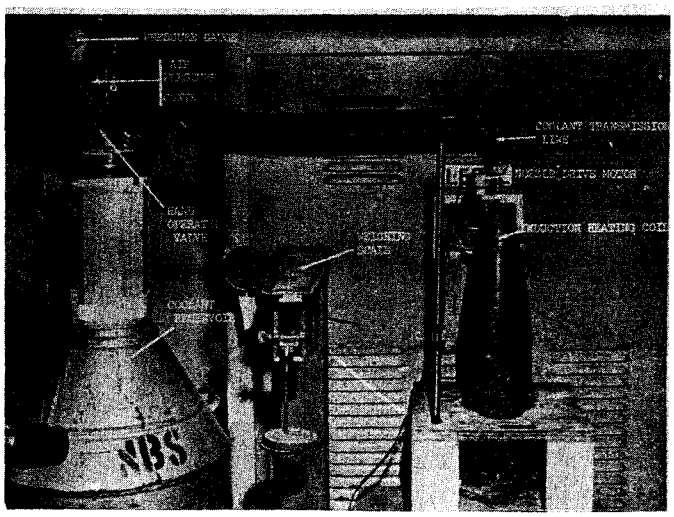


Figure 4. Thermal shock setup

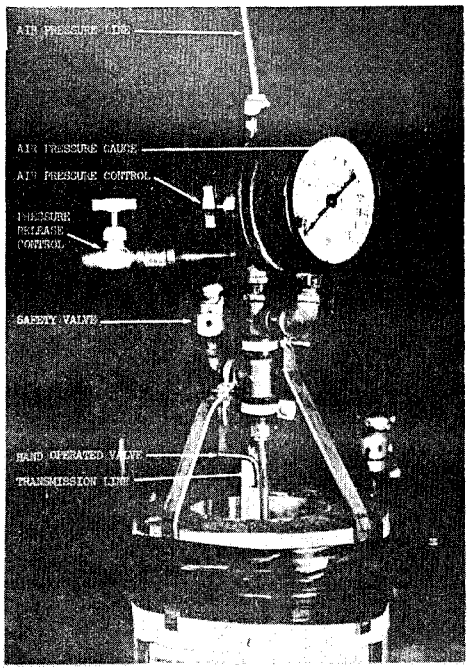


Figure 5. Air pressure controls

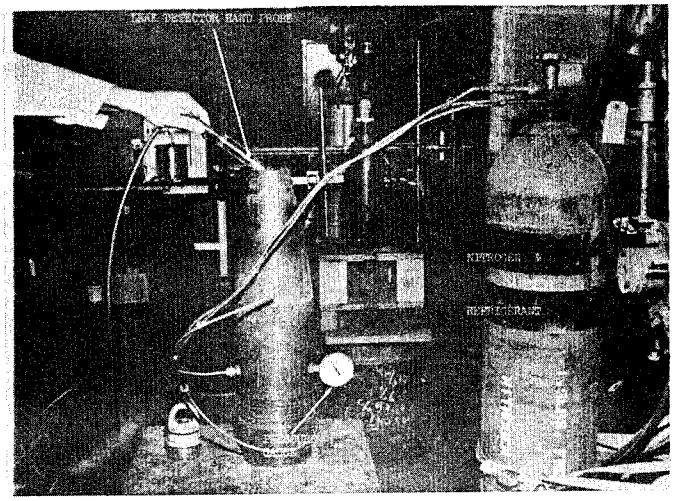
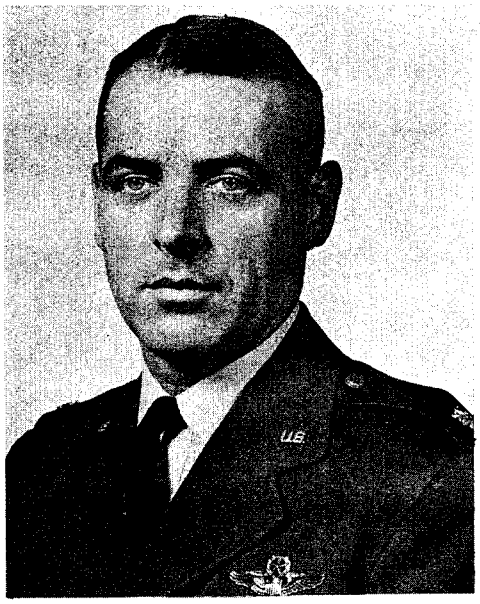


Figure 6. Leak test setup

THIRTEENTH DEFENSE CONFERENCE
ON NONDESTRUCTIVE TESTING
GUEST SPEAKER



Major Robert M. White, principle Air Force X-15 pilot and an Air Force Flight Test Center test pilot since 1955, was graduated from New York University in 1951 with a degree in electrical engineering. He received eight Air Metals for 52 combat missions over Europe in World War II as a P-51 pilot based in England. He was a captive of the Germans for about two months after being shot down by anti-aircraft artillery near Munich. He was a member of the 40th Fighter-Interceptor Squadron, based in Japan from 1951 through 1953. He qualified as an "astronaut" in July 1962 after reaching an altitude of over 59 miles. His awards include: aviation's Harmon Trophy, The Society of Experimental Test Pilots' Iven C. Kincheloe Award, the Robert J. Collier Trophy awarded by President Kennedy, National Aeronautics and Space Administration Distinguished Service Medal and his Astronaut's Wings awarded by Chief of Staff, General Curtis E. LeMay.

PRESENTATION OF MAJOR ROBERT M. WHITE

It's a great pleasure to be here tonight. I think I have to assure you of this in some way. Very many of the people here, at the gathering before dinner, were making so many remarks about their appreciation to me for being here. I thought perhaps I would deviate from what a speaker normally does, wherein he saves his thank you remarks until he has finished his small program. I would like to try to express to you my thanks right at the start. Now this can be a difficult thing to do. It can be done in many ways, and sometimes it is a difficult thing to do most appropriately.

I think of the time in the Southwest when a tall man in a 10 gallon hat walked out of church after the service on Sunday morning. The minister was in front of the church greeting his parishioners as they left. This man approached the minister and said, "Reverend, I think that was a damn fine sermon you gave today". Well, the minister thanked him and said

that he thought he could use a bit more appropriate language in expressing his thanks. And he said, "Yes, you're right, but you know that was such a damn fine sermon that I put a thousand dollars in the collection plate". The minister looked up at him and said, "The hell you did". Thank you.

I feel my task here tonight is to try to give you some introduction to and information about our X-15 Program. In order to do this, I'm going to have to brush over the subject, rather lightly. As you can well imagine, I can go into a great deal of detail in many areas, but I have a two-fold task. I will be speaking to technical people, who would like to hear more of the detail, and to nontechnical people who would rather hear of the things that would be interesting to them without the great technical detail that would either confuse them or bore them, or both. So let me try and tell you something about the Program, why we're doing it and what we think we're accomplishing.

I'd like to go back in time, to start at the very beginning in 1954, well before the Sputnik first appeared over the horizon, well before a research airplane called X-2 flew just a bit over 100,000 feet or three times the speed of sound. In this year there were a number of studies being conducted by several agencies in the government, the Air Force, the Navy and the NACA. National Advisory Committee for Aeronautics is now our National Aeronautics and Space Administration, which I shall refer to as NASA hereafter. Now these people, independently, were thinking about a research airplane that could go out to fairly high speed and go above the earth's atmosphere, a vehicle with which we could take a look at the problems, that may come up in the very distant future, having to do with space flight. This arrived sooner than we thought, didn't it? Well, in 1954, it didn't take long for these people to realize that they were each thinking about these things, so they jointly gathered together in what we call the Research Airplane Committee of NASA and came up with the idea of going ahead with a vehicle. They specified that it should be capable of reaching a Mach number of six, or six times the speed of sound, and fly to an altitude of at least 250,000 feet. This plan was laid before the members of our industrial team, and a competition was held. Eventually the North American Aviation Company in Southern California won the competition, a design competition, and they did produce three X-15 vehicles. We have three airplanes that we have been using in the program.

Since the nature of the program was joint in its effort, the Air Force and the Navy supplying much of the funding, the NASA would be responsible for the technical conduct and the reporting of the results of the program. Since it was a joint affair, pilots from the various agencies, including the prime contractor, would participate; so, we did have a group, a team of pilots from North American, the Navy, the Air Force and NASA joining in the program. This is how it started, essentially, from the beginning.

Well, jumping right up to the present, we can say what we have accomplished in some of those things that make the headlines. We have reached

a speed slightly in excess of Mach six, which is something a little better than 4000 miles per hour, essentially the maximum speed we can obtain with this airplane. We've reached an altitude, just recently, of 314,750 feet, which is just a bit over 59 miles. Now in order to do this, since 1959 we've had to carry the X-15 aloft with a converted B-52 bomber. This technique was used for launching the X-15 on 118 flight attempts. Every time we take off, we're certainly not guaranteed that we're going to launch the X-15. In the countdown procedures, as we activate systems on board the airplane, we do run into problems, technical mechanical difficulties, that will preclude a launch. Well, by the very nature of the way we do the thing, we can abort the mission, return home and land with the X-15. We've done this a number of times. And so, although we've taken off 118 times, we've actually dropped the X-15 on 68 pre-flights.

Specifically, what is the purpose of the X-15 Program? Very generally we can say that, first of all, we're looking at high speed aerodynamics. What happens when we take a certain fixed shape vehicle and fly it at high speed, in the order of Mach numbers, where we've never flown before? What does this mean on this particular shape? How does it fly, and how does it handle? We want to know this. We want to verify what we've learned in the wind tunnels. We get good information from the wind tunnels, from our computer and our analytical studies, but in the final proof of the pudding, we have to fly the vehicle.

Next, we want to look at what the problems would be in controlling a vehicle like this once we get above the earth's atmosphere, where normal control surfaces are no longer effective, because the air molecules are no longer there to bump against the control surfaces and allow us to maneuver the vehicle. Then comes the problem of aerodynamic heating, essentially a new phenomena in the aircraft field, whereby coming back into the atmosphere at high speed, just by virtue that we're having the air in contact with the surface of the airplane at high speed, we're going to heat up the surface to very high temperatures, comparatively high temperatures, in our case over a 1000^{o}F. What kind of structure do we have to have, and what is it going to do to the structure? Will it retain its structural integrity after passing through this environment? Stability and control are concerned in that. Can you fly this vehicle? Can you control it? Can you make this shape stable, so that it doesn't do all sorts of crazy things that a pilot is not happy with? And finally, many people, not the pilots, jumped in on the physiological effects that would be associated with high speed, high altitude flight. There're wondering what happens or what goes on within this creature who has to fly an airplane at very high speed and high altitude. I might say the pilot is more particularly concerned about it. So, physiological effects, let's look at them in great detail, not to see whether or not the fellow shakes when we put him in the airplane or is pale when we pull him out, but let's take a look at him during the course of the flight. They can do this by a unique arrangement which I'll discuss a little bit later. Let me dwell for just a moment on the description, a rough description, of the airplane.

When the airplane was first conceived and the design was attacked, the philosophy behind the design was that the state of the art would not be pushed. In other words, we would not be looking for break-throughs in any one area in order to come up with the finished product and fly the vehicle. It was felt that if we did not accomplish a significant break-through in design of the ship itself or some of the systems on board, we would be defeating our purposes, and we would not be ready to fly at the time the airplane rolled out of the door. So we went ahead with what we felt were known quantities in the state of the art and proceeded with the design in that manner.

Now the airplane, and we'll see some pictures of it, or perhaps you have seen pictures of it, is really not a very radical departure from what you know as an air vehicle. It has a fuselage, wings, a tail section and movable control surfaces. It looks, in a sense, like the airplanes we've known in the past. So it's not really a very radical departure. One region where we made a change, something significantly different, was the amount of vertical stabilizer or rudder area. We have, essentially, an equal amount of rudder below the fuselage as above. The reason for this was to increase the directional stability of the airplane at high Mach numbers. As it turns out, at high velocity, high Mach numbers and high altitudes, we have a very radical loss in the directional stability of the airplane. This occurred in the X-2 airplane, and one means of counteracting this was providing more area. You may think of it as being similar to the tail of a fish. He has an equal amount above his back as below it. If you cut off half of it, he may not have the capability of maintaining his straight path through the water. It's not really too much different with the X-15. The controls of the airplane, as I mentioned, are fairly conventional. We have movable control surfaces so the pilot can maneuver the vehicle. However, these become ineffective when we get outside the atmosphere; so, we use what we call reaction control course with no atmosphere. If we exert an action on the ship, the airplane will react to it. We merely exhaust super heated steam from little rockets in the nose and in the wings. We do this by carrying hydrogen peroxide, and pouring this over a silver catalyst bed. The chemical decomposition results in water vapor and intense heat providing super heated steam. The pilot, with the control handle, can exhaust this super heated steam to maintain the attitude of the vehicle as he desires.

Another thing that was fairly unique in the vehicle, although we see it in many missile systems or systems that depend on a rocket engine, was that it carried auxiliary power units. Aircraft, in the past, have had either the reciprocating engine or a jet engine with rotating machinery to which you can gear auxiliary equipment such as hydraulic pumps for your hydraulic power and electric generators for electrical power. In a rocket engine we do not have any rotating machinery; so, we're interested in providing some sort of a prime mover for the hydraulic pumps and the electric generators. We do it in very much the same manner as I described in the reaction control system. We pour hydrogen peroxide over a silver catalyst

bed, and the decomposition again results in super heated steam. You merely impinge the steam on a turbine wheel. You have a steam turbine, a prime mover, to which you gear your generator and hydraulic pump. We have two of them on board the airplane. Very necessary. If one were to fail, you have the other to back it up.

You might be interested in how we manage to get ourselves to such a high velocity or high altitude. Well, of course this will take me right out into the rocket engine. We have a rocket engine power plant on board made by the Reaction Motors Division of the Thiokol Chemical Company. It develops 57,000 pounds of thrust, the usual way of speaking about the power developed by a rocket engine. Or if you prefer, we can say one-half million horsepower; or if the ladies prefer, they can think of 1,700 Cadillacs tied together, all developing full power, pulling the airplane. Now, how do we develop this thrust? By using liquid propellants, the fuel, ammonia and hydrous ammonia and liquid oxygen. Of course the liquid oxygen again is the oxidizer for the fuel. Because we go above the earth's atmosphere where there is no oxygen, we have to carry our own oxygen aboard, much as they do in any large missile. We have 1,000 gallons of ammonia and 1,500 gallons of liquid oxygen on board. The total quantity of propellant weighs 20,000 pounds. This is quite a bit. We start the engine and we go ahead at full thrust. Just to show you how hungry this engine is and why it develops the power that it does, it consumes this 20,000 pounds of propellant in 83 seconds. It goes through in a hurry, but it develops the push to get us out to the high speeds, and at the end of 83 seconds the engine ceases to operate. We're really a high speed glider when we get to the end of that.

Now some of you may try to visualize what is it like to go 4,000 miles per hour, or wonder what does it mean to me. What significance does it have? I think of doing 60 miles an hour on the highway or perhaps 80, or if you're real foolhardy, 100. I believe it's the New York, New Haven and Hartford Railroad, that advertises "New York to Boston, 90 miles - 90 minutes". Well, at X-15 top speed, "New York to Boston, 90 miles - one minute and 18 seconds". Perhaps that gives you some feel for what the speed is like.

Some of the results that we've had, some of the interesting occurrences, and I think, the philosophy of how we go about our program, might be of interest to you. When I was first approached by Phil Cambis on speaking here, he talked about nondestructive testing. Of course, this appeals to me very greatly, because that's exactly the business we're in. I think, it points up one of the very interesting features of our program, and one of the reasons we who are in it ballyhoo it so much or believe in this way to do testing. We are interested in gathering data. There's a great deal of information that we gather all the time we fly, in getting the vehicle back and in using it repeatedly. As you see, in 68 flights with three airplanes, we have, fortunately, a very successful program. We've been in the program now for a number of years, and I've been asked by some people, "Well, why didn't you get to your designed speed or designed altitude sooner"? I think they were more concerned about us getting a headline sooner. Really, the reason is that we follow the same philosophy

in this program that we have in every flight test program we have done in the airplane business. We go through this thing in a step-by-step process. I assure you, if we had tried to fly the airplanes at maximum speeds and maximum altitudes the first times that we began flying the X-15, we most assuredly would have lost several of the vehicles, because certain things happened in the course of the program to verify this. What we've done, then, is fly the airplane with a crawl before you walk type thinking. When we have analytic information; and wind tunnel information, we go ahead and fly the vehicle out to a certain speed, where we have confidence that we can go. We come back with the information, and either we verify the analytical wind tunnel study information that we have, or determine why there are differences. After doing this, we have increased our confidence to take the next step. We have done just exactly this all through the course of the program.

In addition to that, our method of operating, we feel, has been borne out by several of the things that have happened, nothing drastic, I'm happy to say. However, a number of occurrences have shown up in the course of the program primarily as a result of the aerodynamic heating I talked about. Now the aerodynamic heating, merely by virtue of the fact that the airplane has accepted high temperatures, has caused some structural damage on the airplane. It first showed up along the fuselage and in the side frames, where the airplane is made up of Inconel X Steel. Along the fuselage we had cracks in the skin. Perhaps this explains why, in some of the earlier flights, the pilot came back and talked about the loud banging, clanging, popping noises that he heard after the engine was shut down. It wasn't too hard to imagine, when we saw the cracks in the skin, remembering that the liquid oxygen tank is carrying this lox at -260°F. This is cold enough to put a coating of frost on the skin of the airplane. You launch the vehicle with the skin chilled down to this cold temperature. You go ahead and fly it out, and 83 seconds later you've elevated the skin temperatures in this area to +500 to 700°F. So you can imagine the gradient across the skin, and hence, some of the structural damage. Damage also occurred along the wings. We had some of the wing panels begin to buckle and show signs of damage because of the heating. As we discover these things, we are able to analyze them and make fixes, structural fixes, to preclude something more serious happening when we go to higher speeds and accepted higher temperatures.

I think in this area, one of the most interesting things, as far as the pilot is concerned, has been damage incurred by the windshield. On one early flight of mine, after coming back in from a 217,000 foot flight, the windshield shattered. It remained in place, but it cracked itself up quite morbidly. When we got down to the ground, we looked at this thing. As it turned out, early in the program we had had a glass that was made of one particular material that we decided wouldn't stand the temperature; so, we went to a new glass. As you might suspect, human error is one factor that can creep in. This old glass had been put in the airplane by mistake. Fortunately there was no problem there. So we put in the new glass and made sure that we had the proper windshield in. On another flight, I made too, a high speed flight at 4,000 miles per hour, very

shortly after reaching maximum speed, low and behold, the windshield shattered again. This time to the point of being so opaque that you couldn't see through it. Well, fortunately there are two, one on the left and right. It occurred only on the right side, and it was not sufficient to compromise visibility for landing. As it turned out, it wasn't the glass that failed. The canopy frame, undergoing heating and then cooling, had expanded, contracted and buckled. The canopy frame buckling was enough to put stresses on the glass and shatter it. Well, we learned as we went along, and I think by doing this, we have precluded what might have been some serious difficulties.

There are some factors that are of particular interest to the pilot, or my office in the airplane, that you might be interested in. I'd like to mention first the idea of risk or danger. Several people tonight, again before dinner, talked about, what they thought, was the great inherent risk or danger in doing something like this. Well quite sincerely, I'm not being overly humble, in saying that I don't think there is the element of danger or risk that you imagine. By doing this business the way we attack it, in the step-by-step program, the pilot is well integrated into the program, and he has been in on the design of the vehicle, the flight planning, the evaluation of the results, and planning of how we should go on to programs in the future. I think it really is a matter of how you look at it. The things you don't know about are really the things you are afraid of.

If I might consider the two caterpillars sitting on the limb of a tree. They were there talking, and a little butterfly went flying by. One caterpillar looked at the other and said, "You'd never get me up in that thing".

Well, there are things that are provided for the pilot for his protection, because he is going into a region where the environment is essentially hostile. He has a cabin and cabin pressurization is provided. This is a real necessity, because at those extreme altitudes, you could not survive without artificial pressure on the body. The cabin is pressurized with nitrogen gas, a hostile environment--something we will not accept in the future. You can see in the orbital capsule programs, they are using a breathable atmosphere, where in our vehicle at this time we are not. So while wearing the pressure suit we have to keep the face plate closed, so that we can breathe oxygen. It would have presented a much more severe design problem, at the time the system was designed, to provide a breathable atmosphere. Our system has one advantage in that a pure nitrogen atmosphere will help eliminate fire hazard in the cockpit, since there is no oxygen to support combustion. We have accepted it, and it has worked out well.

In the event the cabin pressure system were to fail, and the cabin to lose pressure, you would be in serious trouble, and that's the reason for the pressure suit. Now I heard one lady, tonight, refer to it as the astronaut suit, as though perhaps this was a badge that the astronaut wears

to identify him or because the silver outer garment looks very nice for picture purposes. But really, it has a much more serious function than that. It provides an artificial atmosphere for the pilot's body in the event the cabin pressure fails. If the cabin pressure fails, sensors will automatically inflate the suit, and you end up like this, but it does protect you. It's an interesting garment. As you wear it, it becomes very hot and uncomfortable. Gas is vented through the suit, nitrogen gas, to help keep you cool, but after exposed to several hours of wear, you find the thing causing you to perspire. It becomes tight and uncomfortable and puts welts on your skin. This doesn't seem incongruous when I consider that the suit was manufactured by the David Clark Company in Worcester, Massachusetts. Now Dave does this sort of thing, but really as a sideline. It's interesting, I think, perhaps to the ladies, that David Clark's main reason for being in the business world is his manufacture of brassieres and girdles.

Now to get to a final phase in the flight, the landing. We do make a sophisticated landing, that is on land. I shouldn't have said that, Captain Savidge has just given me a very severe look. Since we have an air vehicle, it's rather logical that we just go ahead and employ the same technique that we do in landing a conventional airplane. We provide landing gear, as it turns out steel skids, because we're landing on the dry lakes down in Southern California and Nevada, and a conventional nose wheel. We're quite pleased with the fact that we're trying to demonstrate flexibility by having a lifting vehicle, something with wings that will provide lift, that we can maneuver and recover at a specific landing point. One thing we're quite interested in, and have been doing all along, we land at Rogers Dry Lake. You'll notice in the film that you'll see shortly, that we recover on this broad expanse of dry lake bed. We have a 65 square mile area back at Edwards that we can use for emergency or standard operation as we prescribe. Now people, many people think, "Well, you have this area, and you're coming in with a high speed vehicle that's going down in this direction at a very high rate, so you can go ahead and do this". But rather, we mark a specific runway on the lake bed, and before the flight we say that this is the runway on which you are going to land. This is the direction in which you're going to land. Then we mark a little "X" and say that's the spot on which we'd like the airplane to touch down. In the last 25 to 30 flights, as we have been looking statistically at this thing, the pilots have been landing within $\pm$1,200 feet of that spot, which we think very adequately demonstrates the flexibility of recovering a vehicle from a space environment, back into the atmosphere and back down to the designated landing point. And I'm sure, well as a matter of fact I know from speaking with the Mercury people, that they are looking for things like this in the future. After all, I might say that they cannot land their capsule on a specific, designated landing point, but the X-15 cannot go into orbit. So there are compromises for the job we are trying to do, and happily of course, in the future, we are going to combine the best features of each of these systems into something, perhaps, that will be operationally feasible to do.

Just one brief item on the support required for this. We have an extensive range, over which we operate and launch the X-15, several hundred miles from home. We have to fly over a region where there are dry lake beds that we can use for emergency recovery in the event of difficulty. A great number of people have to go out to these places. We send out helicopters, transport airplanes to carry equipment, fire trucks, fighter airplanes to escort the B-52 and the X-15 when its in flight, medical teams and so forth. Although the other pilots and myself do get the larger measure of credit or ballyhoo for doing this program, of course it is the people, and many fine people, who make the difference in the thing being successful. And of course we're interested in it being successful, because each flight that we attempt has a specific purpose. It has to bring back the information that we're looking for, because each flight costs in excess of $100,000. It has to be worth the cost.

I hope I've given you some idea of what we're doing, rather broad I admit, but I have a short film that we are going to run. I will narrate while the film is going on because it's silent. It's in color. You'll see some of the sequences; you'll get a look at the pressure suit; you'll see the B-52 taking off; you'll see a launch. In one sequence--and I'll describe it to you now, because it is rather difficult to pick up during the rather short time it's on the screen--you will see pictures taken from the X-15 during flight. We have a camera mounted in the fuselage of the X-15 looking to the rear. You will see the tail assembly in the picture and of course behind that, the earth, the horizon and the sky. So when I note that this is the camera looking to the rear, perhaps you will be able to get a better perspective of it. We'll go through this thing and finally carry on through to a landing sequence, and then, I'll be back and visit you after it's over.

NARRATIVE DURING FILM

This shows the rocket engine during the ground run on the test stand at Edwards Air Force Base; you can well imagine that engines are run on test stands and checked out prior to the time they are installed in an airplane and operated in flight. This is just one of the facilities we have at Edwards.

You notice the pattern of the flame changes as the pilot throttles the engine. A unique and very significant feature in this rocket engine is that the pilot has control over the amount of thrust the engine develops by throttling, as well as the capability to shut down and restart the engine in flight.

Here you see a special van, air-conditioned with appropriate facilities, where the pilot dresses in his pressure suit and has all the special sensors applied to his body, so that they can look at his heart rate and respiration rate.

Here we're at the scene where the X-15 is mated to the B-52. You can see that the pilot enters right here on the ground. In the past, the rocket airplane was mounted in the bomb bay of one of these airplanes and the pilot got on board during flight; now however, it begins right from the ground. So we go through a rather elaborate procedure here while the pilot gets on board. They tie him in rather securely. We finally get to the point where we're ready to go, and the B-52 moves on out. Taxiing out. Here you can notice the X-15 tucked up under the right wing and the specially designed pylon to carry the airplane.

There are two methods of launching the X-15. The B-52 pilot can throw a switch to drop him off, or the X-15 pilot can launch himself. Early in the program, we had the B-52 pilot launching at the countdown. These days the X-15 pilot launches himself.

And here we are in flight, you can see the white frost around the airplane from the ammonia and the liquid oxygen tanks. As the airplane progresses toward the launch point, we are activating many of the systems on board and going through the countdown procedure. As each system checks out, telemetered information is validating what's going on aboard the airplane. We can proceed to a launch, or as I described before, in some cases, a no launch. In case of an abort, we would jettison all of our propellants, and the whole bunch would come back home.

There you see one of the airplanes flying close by, making observations external to the airplane that no one else would be able to see, another assist to the pilot in the X-15. It's a rather comfortable seat.

Here they are doing a jettison check, you notice how the upper tails stick right through a slot in the wing. And there's the drop. Immediately after launch, the pilot lights the engine, and then he immediately departs. Now, this is taken from one of the chase airplanes. The chase airplane is traveling along about 400 miles per hour. You can see the X-15 beginning to curve up, and it's establishing a climb to follow a trajectory for that particular flight.

Here we are looking to the rear of the airplane again. We're on board. You begin to see earth curvature, although not as distinctly as the pilot can. And there, we're back looking at it from above. When he leaves the earth's atmosphere, that contrail will leave. Here again, looking at the back end of the X-15, you get some idea of the panoramic view limited by the frame of the camera. You can imagine the pilot being able to look completely from side to side covering the horizon. It becomes much more dramatic.

Now here we are coming in for the landing. Notice the lower tail will be dropped, we didn't see it. Here's the landing gear down, rather an ungainly looking creature as it comes in for a landing. It begins at 300 miles per hour then gradually slows and touches down at about 210 miles per hour. The airplane continues for its slideout for just over one mile.

With the main landing skids, being at the very aft end of the airplane, you notice that the pilot is unable to hold the nose up, once ground contact is made, and a rather severe impact on the nose gear immediately after main gear touchdown.

And of course the gang arrives. The fellow in the orange flying suit always comes up to the airplane, looks through the windshield, and you have to give him the high-sign, you know, thumbs up. If he knows you're all right, he'll stand there and wait for you. If you don't give him the high-sign, he's going to start doing things rather quickly.

And of course, just closing out sequences, here's where you begin to relax very thoroughly. We still have hydrogen peroxide on board the airplane, that's why the fire people are around. There is a potential fire hazard, not an explosion hazard really, but fire hazard; so, these people are standing by in the usual manner that they do. This was taken quite a while back in one of the earlier flights, and this will bring it to an end.

Well that's just a brief look. I hope it gives you some idea of what it all looks like. The program is not quite finished yet. We're taking a look at some higher altitudes before we conclude the research portion of the program. We're taking a good look at this, and focusing the attention of a lot of our people on being able to go something higher than the last flight flown. There will be following programs. It turned out recently, the X-15 was truly a research airplane. It did not have any utility value. It was not a military vehicle, a transfer vehicle, or what have you. However, because it is a successful vehicle, and one that can go up into a unique region. This region is well above the area where balloons can fly; it's above the earth's atmosphere, but less than orbital altitude. A number of people have come in, and we're going to carry out more experiments on board the airplane, with horizon scanners, star-trackers and cameras to take photographs of shock waves, and so forth. So the program will continue for several years. We feel that some additional information will be gained, particularly for those people who are interested in some of the experiments which will be carried out.

In addition to that, we have an Air Force program that's going to come along, hopefully, called the Dynasoar, or the X-20. Where again we have a main vehicle, which would be boosted off by a Titan booster. We will fly around the world in one or more orbits and make a re-entry into the atmosphere, with the ability to maneuver and control in the atmosphere with some flexibility, completing the re-entry and then recovering. We feel this will be another extension in our space effort to fly a vehicle with some flexibility and one that can be used again. So we're quite proud of the program.

Rowand. The nominating committee has nominated three individuals to fill the vacancies occurring after this conference. The individuals nominated are:

Mr. Harold Baller, Army C.B.R. Quality Assurance Group, Edgewood Arsenal, Maryland

Mr. Bernard W. Boisvert, Overhaul and Repair Department, Naval Air Station, Jacksonville, Florida

Mr. Edward McKelvey, Air Force, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio

Those named expressed willingness to accept the responsibility. If there are no further nominations from the floor, a motion to accept the nominating committees nominations is in order. (Motion carried.)

THIRTEENTH DEFENSE CONFERENCE ON NONDESTRUCTIVE TESTING

TOUR OF NAVWPNSTA CONCORD NDT FACILITIES

Demonstration of Nondestructive Test Equipment and Methods

(1) Q. E. LABORATORY BUILDING IA-58

X-RAY EQUIPMENT

10 Mev - Varian Associates Linear Accelerator
2 Mev - General Electric Resotron
250 Kvp - General Electric OX-250
150 Kv - Norelco 150 Kvcp Fractional Focus Unit
15-50 Kv - Norelco with EG-50 Tube
250 Kv - Triplett & Barton Portable Unit

IMAGE SYSTEMS

Fluoroscopy - 150 Kv Direct Viewing
Image Amplifier - Norelco at 150 Kvcp

ISOTOPES

50 Curies $Iridium^{192}$,
15 Curies $Cobalt^{60}$ - Nuclear Systems Multitron

MAGNETIC PARTICLE

Liquid
Dry
Fluorescent - Magnaflux Equipment

PENETRANTS

Fluorescent
Dye

(2) Q. E. LABORATORY BUILDING IA-22

ULTRASONIC

Attenuation Measurement
Brown University Mark XVII Unit
Brown University Mark XVIII Unit
Low Frequency Ultrasonic Unit Mark XXI

ULTRASONIC (Cont'd)

Flaw Detection
- Reflectoscope - Sperry Type UR
- Sonoray - Branson Instrument
- Reflectoscope - Sperry Model UM 700

Immersion
- Immerscope - Curtiss-Wright

Thickness and Bond
- Vidigage - Branson Instrument
- T/B Tester - Sperry
- Sonizon - Magnaflux Corporation
- Audigage - Branson Instrument

EDDY CURRENT

- Magnatest - FS 310 - Magnaflux Corporation
- Magnatest - FW 110 - Magnaflux Corporation
- DuMont Cyclograph - J. W. Dice Company
- Magnatest - ED 500 - Magnaflux Corporation

ION CHAMBER AND SCINTILLATION DETECTION

- Scintillation Detector Spectrometry Equipment - Tracerlab

(3) X-RAY DIFFRACTION AND SPECTROGRAPHY

- XRD-5 Unit - General Electric X-ray Company
- 21-130 Mass Spectrometer - Consolidated Electrodynamics

VIBRATION - IMPEDANCE (MECHANICAL)

- Endevco Corporation Units
- M. B. Shaker

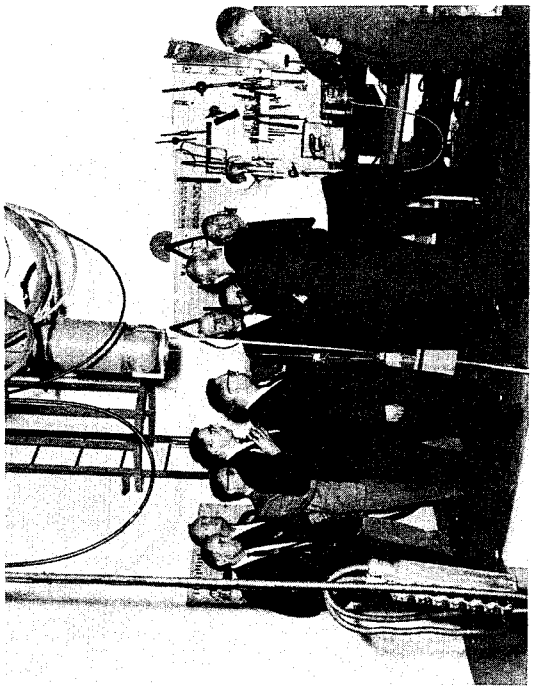
AUTOMATIC FILM SCANNING

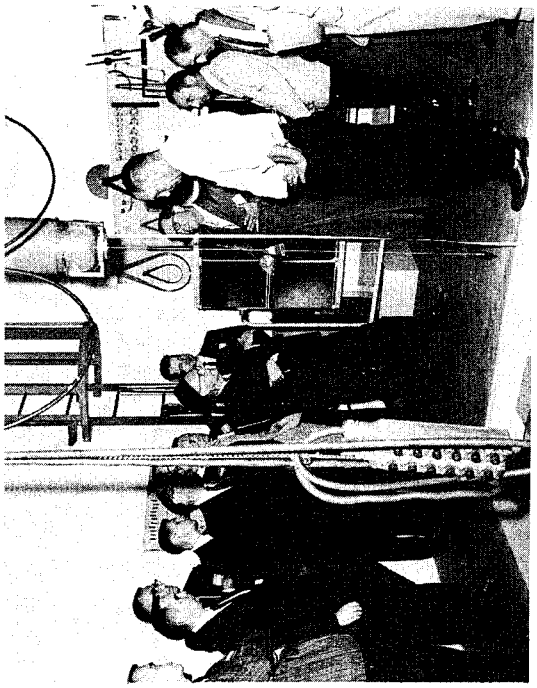
- Jarrell-Ash Microphotometer
- Macbeth Quanta-Log

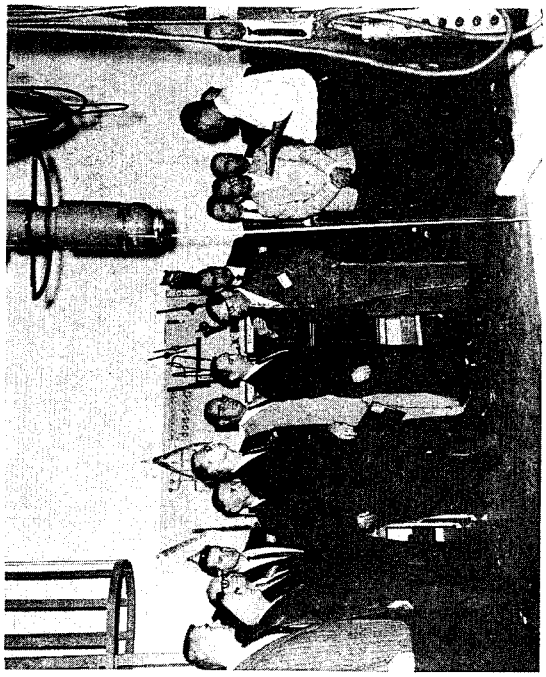
(4) ANALOG DIGITAL AUTOMATIC PROGRAM TESTER (ADAPT)

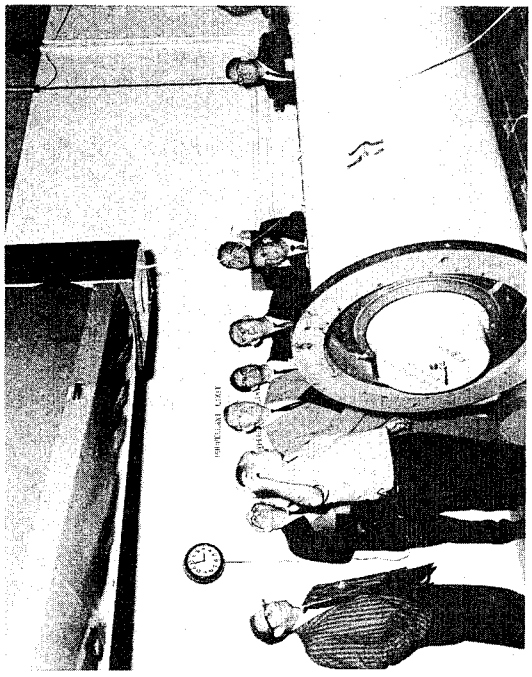
(5) Q. E. LABORATORY BUILDING IA-21

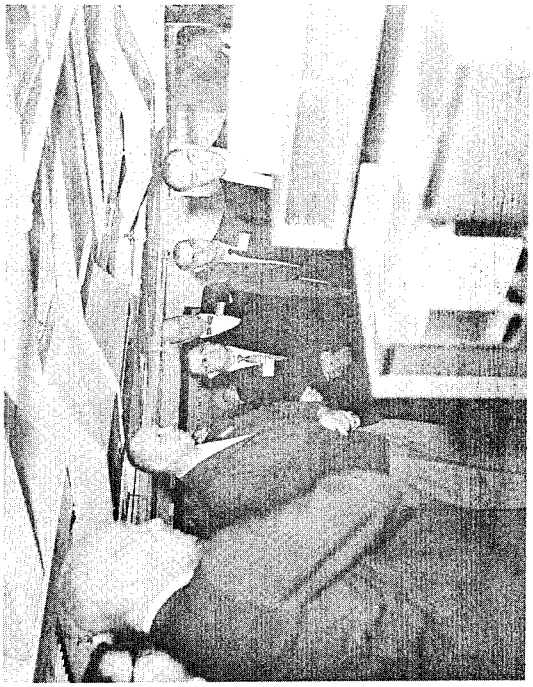
REMINGTON-RAND UNIVAC SOLID-STATE 80 COMPUTER

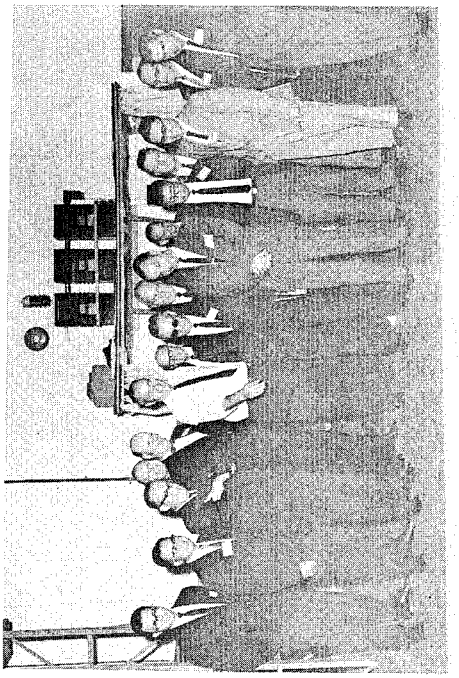


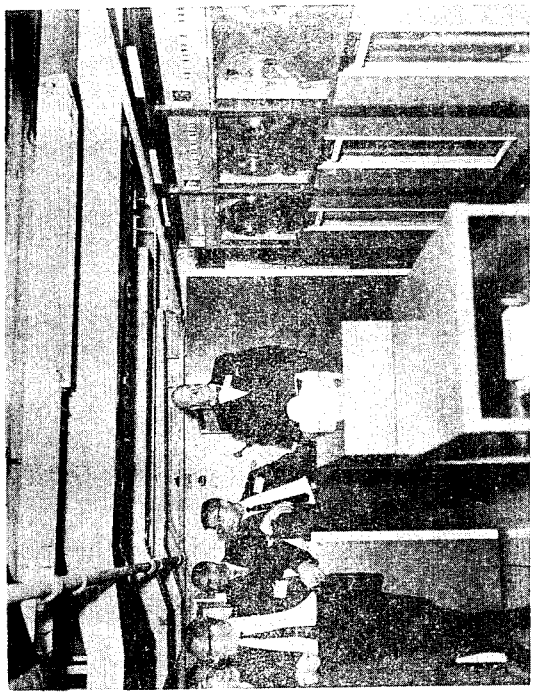


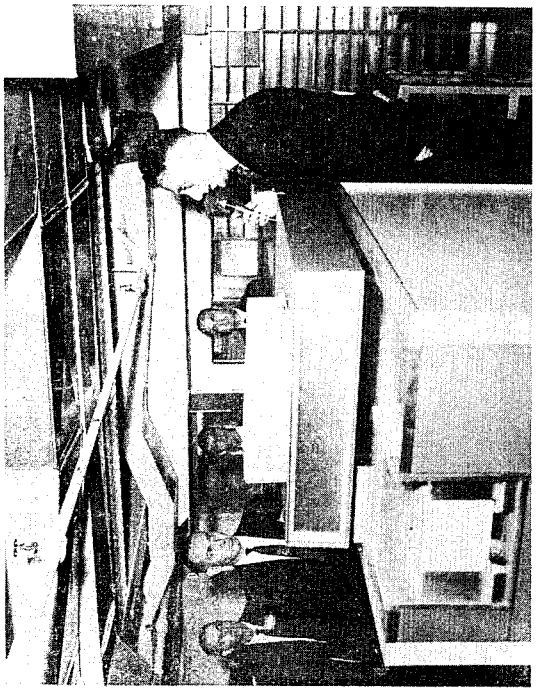


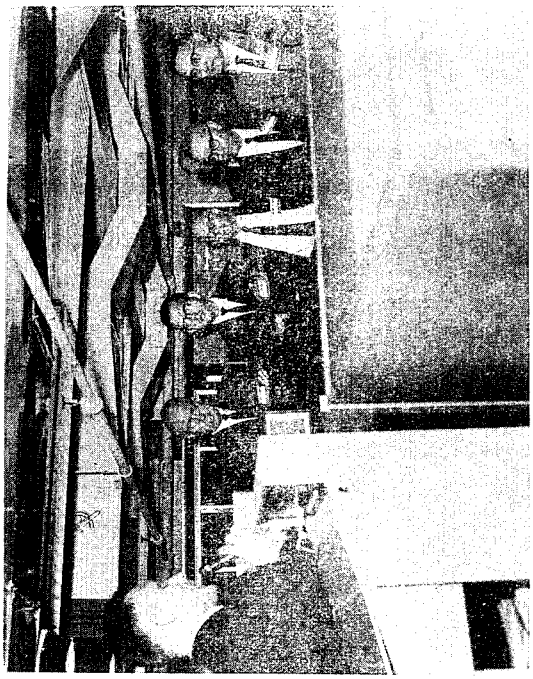


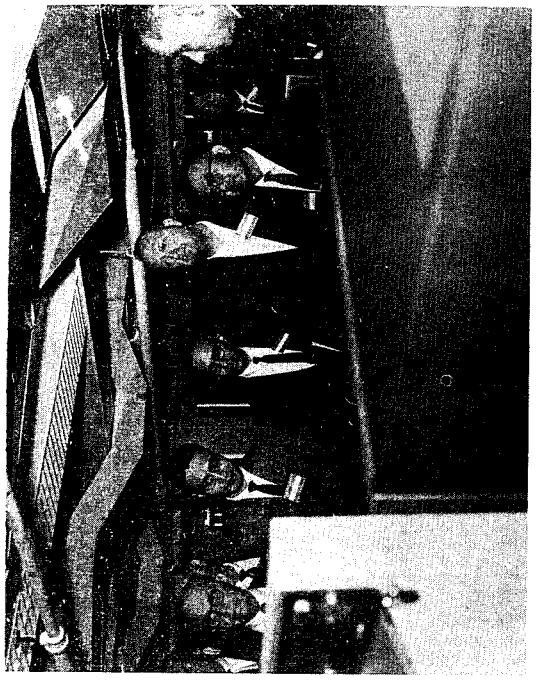












THIRTEENTH DEFENSE CONFERENCE
ON
NONDESTRUCTIVE TESTING

ATTENDEES

Ahlberg, Harry T.	Rock Island Arsenal (Code SWERI-5000) Rock Island, Illinois
Baller, Harold A.	U. S. Army CBR Agency (Code SMUQA-EM) Quality Assurance Group Edgewocd Arsenal, Maryland
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Schindler, Paul	Picatinny Arsenal (Code SMUPA-DC5) Dover, New Jersey
Schrader, Frank G.	U. S. Naval Air Station (Code 341) O&R Department Alameda, California
Schwab, Kenneth I.	U. S. Naval Torpedo Station (Code 3351.1) Keyport, Washington
Sharp, Alfred L.	Tinker Air Force Base (Code OCNEAS) Oklahoma City Air Materiel Area Oklahoma City, Oklahoma
Sheppard, William M.	Robins Air Force Base (Code WRMQQC) Robins Air Force Base, Georgia
Skinner, Wilson F.	U. S. Naval Weapons Station U. S. Naval Mine Engineering Facility Yorktown, Virginia
Smith, W. L.	Lake City Ordnance Plant (Code SMULC-IE-Q) Independence, Missouri
Stein, David	Picatinny Arsenal (Code SMUPA-ND2) Dover, New Jersey
Stout, Frank	White Sands Missile Range (Code EML-STEWS-TED-E) Rocket Vehicle Laboratory White Sands Missile Range, New Mexico
Susich, George	U. S. Army Quartermaster Research and Engineering Center Natick, Massachusetts
Szanto, Joseph	Springfield Armory (Code SWESP-PRD) Springfield, Massachusetts
Tant, Earl R.	Redstone Arsenal (Code AMSMI-RTFN) U. S. Army Missile Command Huntsville, Alabama
Thomas, Wallace K.	Redstone Arsenal (Code AMSMI-IES) U. S. Army Missile Command Huntsville, Alabama

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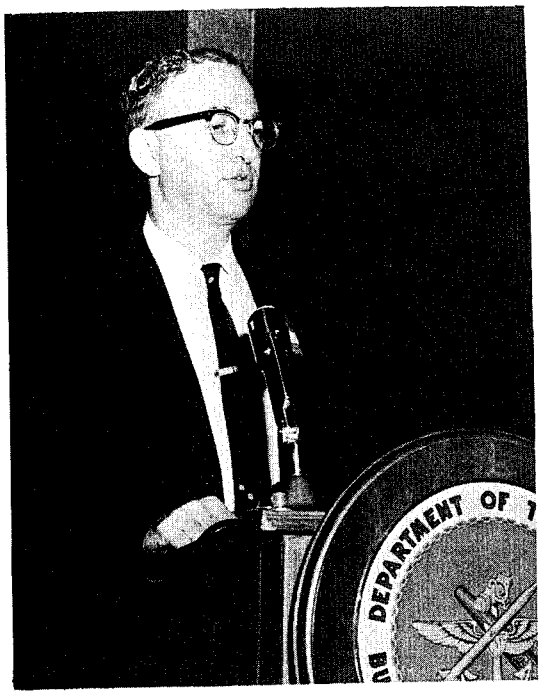
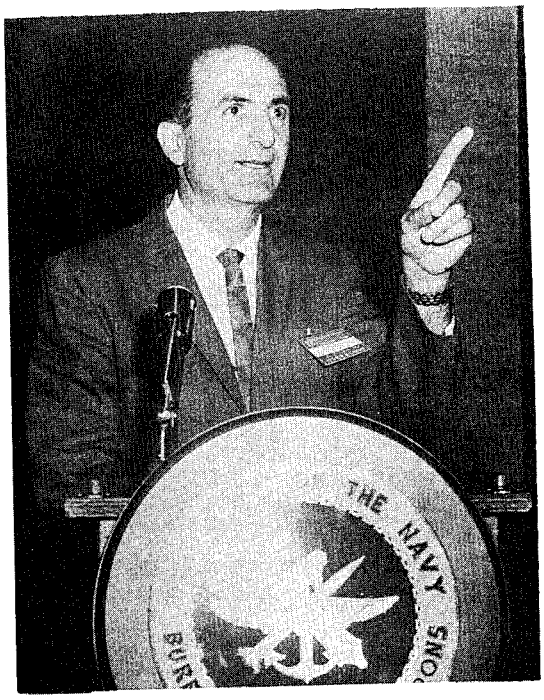
Walker, Wallace L.	U. S. Naval Ammunition Depot Crane, Indiana
Walsh, Myron F.	U. S. Naval Weapons Station Quality Evaluation Laboratory Concord, California
Westby, Harold C.	U. S. Naval Weapons Station Quality Evaluation Laboratory Concord, California
White, Cecil G.	Picatinny Arsenal Bldg. 407 Dover, New Jersey
Wishard, William N.	U. S. Naval Weapons Laboratory (Code TRP) Dahlgren, Virginia
Zagorites, Harry A.	U. S. Naval Radiological Laboratory (Code 942) San Francisco, California

CONFERENCE PHOTOGRAPHS



Solomon Goldspiel
N. Y. Naval Shipyard



Domenic J. Molella
Picatinny Arsenal

Alfred L. Sharp
Oklahoma City Air Materiel Area

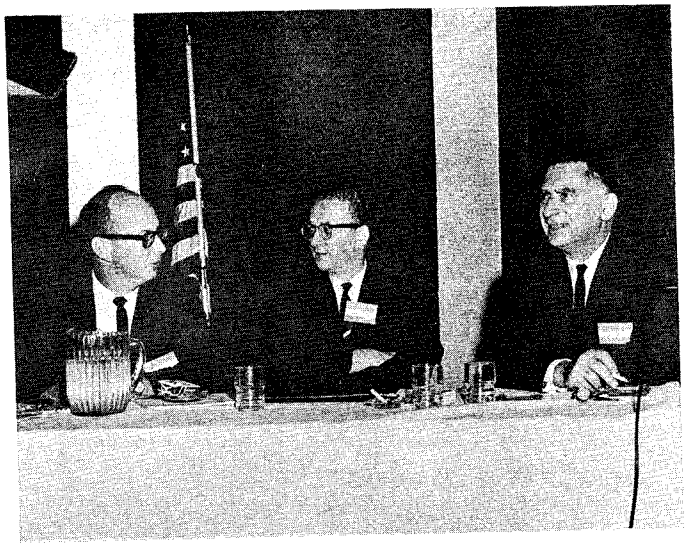
Irving Feinberg
Naval Ordnance Laboratory, White Oak

David Stein
Picatinny Arsenal

Richard R. Rowand
Wright-Patterson Air Force Base

Harold A. Baller
Edgewood Arsenal

Dr. Tung-Ming Lee
Cold Regions Research Engineering Laboratory



Richard R. Rowand, Solomon Goldspiel, Irving Feinberg

Betty Mann, George Deeds and Dolores Romano

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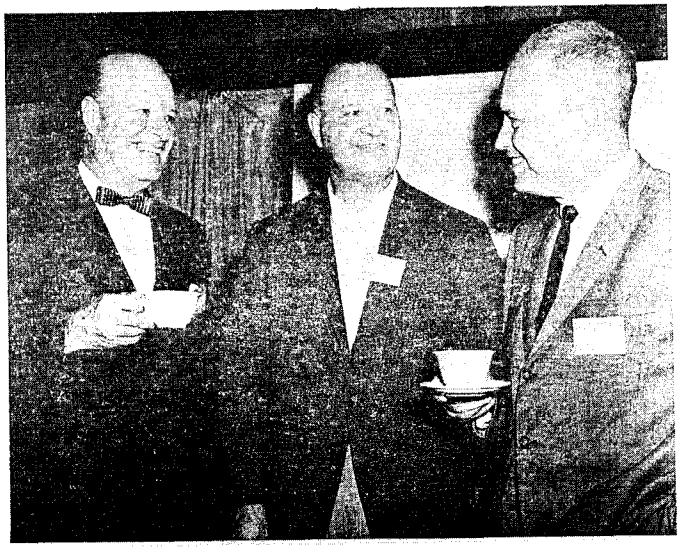
Mildred Patterson, Bernard W. Boisvert

John Orner, Eugene Roffman, Cecil White,
Stephen Hart, Edward McKelvey



Stanley W. Broom, Kenneth I. Schwab, Joseph Szanto

Conference in Session

LOCATIONS AND DATES OF PREVIOUS CONFERENCES

Organizational Meeting, Watertown Arsenal, Watertown, Massachusetts	3-4 Oct 51
2nd Conference, Frankford Arsenal, Philadelphia, Pennsylvania	23-24 Jan 52
3rd Conference, U. S. Naval Gun Factory, Washington, D. C.	19-20 Nov 52
4th Conference, Research and Development Laboratories, Fort Belvoir, Virginia	17-18 Mar 54
5th Conference, Naval Ordnance Plant, Indianapolis, Indiana	16-17 Mar 55
6th Conference, Detroit Arsenal, Centerline, Michigan	9-10 Mar 56
7th Conference, U. S. Naval Ordnance Test Station, China Lake, California	19-20 Feb 57
8th Conference, San Antonio Air Materiel Area, Kelly Air Force Base, Texas	4-5 Dec 57
9th Conference, Army Ballistic Missile Agency, Redstone Arsenal, Alabama	15-16 Oct 58
10th Conference, Naval Air Material Center, Philadelphia, Pennsylvania	6-7 Oct 59
11th Conference, Oklahoma City Material Area, Tinker Air Force Base, Oklahoma	13-15 Sep 60
12th Conference, Quartermaster Research & Engineering Center, Natick, Massachusetts	28-30 Aug 61

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--   TECHNICAL REPORTS STATISTICS  PAGE  1 OF  2  MAY 22, 1992

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--                          ***DTIC DOES NOT HAVE THIS ITEM***
-- 1 -  AD NUMBER: D406539
-- 3 -  ENTRY CLASSIFICATION:    UNCLASSIFIED
-- 5 -  CORPORATE AUTHOR: NAVAL WEAPONS STATION  CONCORD CALIF*
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--       ON NONDESTRUCTIVE TESTING 25-27 SEP 62, CONCORD, CA. SPONSORED BY
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--27 -  ABSTRACT:   SIX PROBLEM CASES ARE PRESENTED. THESE ARE:
--       NONDESTRUCTIVE EVALUATION DETERIORATION OF STORED TR AND ART
--       MICROWAVE GAS-SWITCHING TUBES, QUALITY OF WELD BOND AND PRESENCE OF
--       BLOW HOLES IN RESISTANCE BUTT WELDED BALL ASSENBLY OF 40 MM, M407
--       CARTRIDGE, DETECTION OF CORROSION IN AIRCRAFT INTEGRAL WING TANKS,
--       DETERMINATION OF PROPER SEATING OF RATATING BANDS FOR 105MM HE
--       STEEL SHELL, M14 RIFLE FIBERGLASS REINFORCED PLASTIC STOCKS, AND
--       SUBSTITUTION OF NONDESTRUCTIVE TEST METHOD FOR MERCUROUS NITRATE

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--       TEST OF BRASS CARTRIDGE CASES. IN ADDITION THERE ARE FIVE TECHNICAL
--       PAPERS COVERING VARIOUS ASPECTS OF NONDESTRUCTIVE TESTING METHODS.
--       (AUTHOR).
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